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*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

## *Volume VIII, Part B*

*Chapter 8, Sections 8.4 through 8.7;*
*Glossary and Acronyms*

*December 1988*

*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

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*Nuclear Waste Policy Act*
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# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

*Volume VIII, Part B*

*Chapter 8, Section 8.4, Planned Site Preparation Activities*

*December 1988*

*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

# 8.4 PLANNED SITE CHARACTERIZATION ACTIVITIES AND POTENTIAL PERFORMANCE IMPACTS

This section presents the plans for surface-based activities (including drilling, trenching, and site preparation) and for subsurface excavations related to implementing the site characterization program described in Section 8.3. Also provided are background information on the DOE approach to site characterization, the rationale for the proposed testing configuration, the relationship of that configuration to the repository conceptual design, and the potential impact of the testing activities on the integrity of the site. Further, this section presents information on related topics derived from recent interactions between the DOE and the NRC. Information presented includes the approach to characterizing the primary barrier to radionuclide migration (the Calico Hills Formation), a description of the exploratory shaft facility (ESF) design and surface-based testing activities with evaluations of interferences between tests, and a discussion of the bases for selecting shaft locations and the potential impact of these locations on site characterization and long-term impacts on postclosure performance.

This section is divided into three subsections. Section 8.4.1 presents background information on the approach adopted by the DOE to guide the characterization program, gives the approach to incorporating the requirements of 10 CFR Part 60 in the development of the testing program, and discusses the concepts of flow in the unsaturated zone. An understanding of the concepts of unsaturated-zone flow is a prerequisite for understanding the potential impacts of testing activities on site integrity. Section 8.4.2 presents the rationale for the planned testing, describes the surface testing and the underground test facility, and evaluates the effectiveness of the proposed configuration in terms of test-to-test and construction-to-test interferences and compatibility of the ESF with the repository design. Section 8.4.3 evaluates the impact of the testing configuration on the integrity of the site by considering its potential impacts on the postclosure performance objectives.

There are important ties between the information presented in this chapter and the quality assurance program that governs the activities related to characterization and design. The quality assurance program for site characterization is described in Section 8.6. A quality assurance program compatible with 10 CFR 60 Subpart G will be in place before undertaking new site characterization work to ensure that, as a minimum, items important to safety, barriers important to waste isolation, and activities that could affect the performance of either are designed, investigated, or carried out under appropriate quality assurance controls. The site characterization program activities have the potential to affect natural barriers important to waste isolation; assessment of this potential is a primary topic of Section 8.4. Assessments to determine those barriers that are important to waste isolation are summarized in Section 6.1.5; they are presently based primarily on the results of the performance allocation process described in Sections 8.2 and 8.3. The list of activities that have the potential to affect natural barriers important to isolation is given in Section 8.6 and these activities are a recurrent topic in Section 8.4.

With respect to potential preclosure impacts, site characterization activities are not expected to have any adverse impacts on structures,

systems, and components important to safety. These structures, systems, and components, which are identified in Section 6.1.4, will be constructed after site characterization activities have been completed. The repository designers can consider the possible effects of these activities and if any adverse effects are identified, they can be mitigated in the design. Therefore, the discussion of potential impacts from site characterization activities throughout Section 8.4 focuses on postclosure performance.

*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

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*Chapter 8, Section 8.4.1, Introduction*

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## 8.4.1 INTRODUCTION

This section is divided into three subsections. The first section, 8.4.1.1, describes the phased approach adopted by the DOE to guide the site characterization program. This approach provides for the continual evaluation of the adequacy of the testing configuration and the impacts of the testing activities on site integrity. Next, the approach for incorporating the requirements of 10 CFR Part 60 in the development of the site characterization program is presented in Section 8.4.1.2. Finally, Section 8.4.1.3 discusses the concepts of unsaturated flow and their application to Yucca Mountain. The unsaturated zone is the primary element that the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site. Thus, an understanding of the concepts of unsaturated-zone flow is a prerequisite for understanding the potential impacts of testing activities on site integrity.

### 8.4.1.1 Phased approach to implementing site characterization activities

In managing the implementation of the site characterization program, the DOE must continually evaluate the adequacy of the testing configuration and the impacts of the testing activities on the integrity of the site. This means that regular evaluations will be made of such factors as (1) the potential for interference (test-to-test, construction-to-test, etc.) that could affect the integrity of data being collected; (2) the representativeness of the testing program; (3) the potential for significant adverse impacts on the isolation features of the site; and (4) the design features that reduce the potential for interference and impacts. Consequently, the DOE has established a phased approach to implementing the ESF portion of the site characterization program in which periodic evaluations using available data are made to determine the prudence of proceeding with the next phase of activities. In accordance with the approach, the data collection activities can be generally divided into three distinct phases corresponding to major program milestones associated with the exploratory shaft facility (described in Section 8.4.2.3):

1. Before the start of shaft sinking.

2. During the sinking of the exploratory shafts, ending with the completion of the breakout room at the main test level.

3. In situ testing after completion of the shaft-to-shaft connection at the main test level.

At the end of each phase or before beginning subsequent phases, a review will be held to reevaluate the conclusions and analyses from the information gained from activities performed. These evaluations will be similar to those presented in the balance of this section. The first of the three phases identified is in progress and analyses are summarized in this section. The results of the completion of phase 1 analyses and the conduct of phases 2 and 3 will be presented in semiannual progress reports, thus allowing opportunity to provide information to the NRC, the State of Nevada, and other interested parties. Further, information from the periodic evaluations will be used to

modify or refine the construction and testing activities associated with ESF, thereby incorporating the most recent knowledge of the in situ characteristics at Yucca Mountain. The reviews discussed above will supplement the reviews that are part of the process for completion of individual testing activities. The DOE's approach to implementing site characterization activities provides several well-defined opportunities to reevaluate the conclusions drawn in this section and reassess their validity in light of better information than that which is currently available. The information to be gained during the site characterization activities following issuance of the SCP is expected to be better in the sense that uncertainty will be reduced, assumptions and models will be confirmed or modified, design concepts will be refined, system interfaces and performance will be better understood, and the quality assurance program will place stricter controls on aspects of the program.

The progression of characterization and design activities naturally improves the program data bases in several respects. First, the DOE has an expressed commitment to receive NRC acceptance of its QA program before beginning new characterization activities. The data acquired under such an approved program typically will be more readily acceptable to the NRC staff than data drawn heavily from journal literature or collected under QA programs not approved by the NRC. Collection of data during characterization activities following issuance of the SCP will strengthen the statistical bases for data sets as well as fill in gaps in sparse or limited data sets. Such data will be reported in semiannual progress reports to inform the NRC and the State of the results of characterization activities. It is prudent to plan to use that data to reaffirm the assumptions, data, analyses and conclusions that form the bases for Section 8.4.

As the data collection programs progress, ongoing design activities lead to a refined understanding of system interfaces; likewise, performance modeling activities and the assumptions and models upon which they are based are refined. The improved understanding of the design and the improved capability to viably model performance that accompany the collection of additional data provide the means to reevaluate the conclusions that are contained in this section. The DOE is firmly committed to such reevaluations and plans to report on their results in semiannual progress reports. The actual reevaluations are envisioned to be a nearly continuous process throughout characterization; as noted previously, however, a total reevaluation of the results reported in Section 8.4 is planned before development of the main test level facility. The evaluations provided in this section and those included in the planned reviews focus on the effectiveness of the testing program to obtain needed information. The evaluations include determining if the activities will provide representative data of the site as a whole, if there is a potential for interference between or among construction and testing activities, and if the activities have a potential impact on the ability of the site to meet the postclosure performance objective.

The evaluations of the ESF summarized in the following sections of 8.4 address the location of the shafts, the layout of the underground facility, and the construction and testing operation. Assessments are made of interferences between shafts, interferences between shaft and facility construction and the tests, interferences between tests, and the integration of the ESF with the repository design. The postclosure impacts are assessed by

evaluating the impact of the excavations on the unsaturated flow system. Primary emphasis is given to the potential for fluid movement in or near the excavation and consideration of the types of materials used in the construction and testing operations. This information is used to examine the rationale for the exploratory shaft layout and, in turn, incorporated into the design process to modify the configuration if necessary. Similar evaluations are performed for surface-based testing activities, thereby allowing appropriate definition of construction activities and controls on the drilling operations. In addition, these evaluations allow the identification of specific data necessary to refine the analyses. This provides guidance to the site characterization activities by identifying those data to be confirmed early in the testing program.

### 8.4.1.2 Incorporation of 10 CFR Part 60 in the development of the site characterization program

The development of the site characterization program and the evaluation of the impact of site characterization activities on the integrity of the site have been based on numerous regulations and requirements. These requirements have been considered in the development of Section 8.4, the definition of the site investigations, and the design of the exploratory shaft facility. In 10 CFR Part 60, the NRC prescribes the technical criteria applicable to the licensing of a geologic repository. Many subparts of 10 CFR Part 60 must be considered during site characterization to ensure that the proposed characterization activities will not only allow the DOE to obtain the necessary data for a license application, but also to ensure that the activities will be carried out in a manner consistent with meeting licensing requirements for maintaining site integrity and consistency with the repository design. This section summarizes the site characterization activities, including the drilling and construction activities, and evaluates those activities to determine if they are consistent with the requirements of 10 CFR Part 60. This section (8.4.1.2) identifies those portions of 10 CFR Part 60 directly considered in developing Section 8.4; identifies in general terms the influence these regulations have had on the planned characterization activities and testing; and directs the reader to specific sections containing additional information on how the regulation has been considered. The design of the exploratory shaft has also incorporated the requirements of 10 CFR Part 60 by making these requirements a formal part of the design requirements and design control process. This design control process is further discussed in Section 8.4.2.3.3.

At this very early stage of planning a repository, the most directly applicable sections of 10 CFR Part 60 are related to the preapplication review discussions in Subpart B (Licenses). The requirements for a site characterization plan are established in Section 60.16 of 10 CFR Part 60, while Sections 60.15 and 60.17 of 10 CFR Part 60 establish the requirements for the characterization program content and scope. A summary of the principal requirements of these CFR sections that directly affect site characterization planning and performance impact evaluation is provided in Table 8.4.1-1. These sections recognize three important concepts that form the basis for the descriptions and evaluations presented in Section 8.4:

Table 8.4.1-1. Principal requirements of 10 CFR Part 60 affecting site characterization planning and performance impact evaluation related to discussions in Section 8.4 (page 1 of 2)

| 10 CFR 60 Citation | Principal requirements | 8.4 Section |
|---|---|---|
| Subpart B | | |
| 60.15 Site characterization | The U.S. Department of Energy shall conduct site characterization program | |
| | (a) Prior to license application | |
| | (b) Including in situ exploration and testing at depths waste would be emplaced | 8.4.2.1.4 and 8.4.2.3.3 |
| | (d) The program of site characterization shall be conducted in accordance with: | |
| | (1) Limiting adverse effects on the long-term performance of the geologic repository to the extent practical | 8.4.3.3 |
| | (2) Limiting number of exploratory boreholes and shafts to the extent practical consistent with obtaining the information needed for site characterization | 8.4.2.1.4 and 8.4.3.3.3 |
| | (3) Locating to the extent practical exploratory boreholes and shafts in the geologic repository operations area to where shafts or large unexcavated pillars are planned for the underground facility | 8.4.2.1.4, 8.4.2.3.4.3, and 8.4.3.3 |

Table 8.4.1-1. Principal requirements of 10 CFR Part 60 affecting site characterization planning and performance impact evaluation related to discussions in Section 8.4 (page 2 of 2)

| 10 CFR 60 Citation | Principal requirements | 8.4 Section |
|---|---|---|
| 60.15 Site characterization (continued) | (4) Planning and coordinating subsurface exploratory drilling, excavation, and in situ testing with geologic repository operations area design and construction | 8.4.2.3.6.3 |
| 60.17 Contents of site characterization plan (SCP) | SCP shall contain | |
| | (a) General plan for site characterization activities to include: | |
| | (2) Description of site characterization activities including | |
| | (i) Extent of planned excavations | 8.4.2.3.3 |
| | (ii) Plans for onsite testing with radioactive materials | 8.4.2.3.1 and 8.4.2.2.2 |
| | (iii) Plans for investigation that may affect capability to isolate waste | 8.4.2.1 and 8.4.3.2.5 |
| | (iv) Plans to control adverse impacts of site characterization activities important to safety or waste isolation | 8.4.2.1.2 and 8.4.2.3.6 |

1. The need to balance the testing program for site characterization with the necessity to limit the potential impacts of site characterization on barriers relied on to meet the NRC postclosure performance objectives.

2. The need to have plans for controlling the potential adverse impacts of the characterization activities.

3. The need to integrate the planned site characterization activities with the design of the repository.

Section 8.4.2 summarizes the testing program for site characterization from the more detailed information in Section 8.3.1 and emphasizes those aspects of the characterization program that could potentially impact barriers relied on to meet the NRC postclosure performance objectives. Section 8.4.2 also describes the construction activities and operations needed at the site to carry out the site characterization program and discusses the control of adverse impacts and integration with repository design. The final section (8.4.3), then describes the potential impacts of the site characterization activities on postclosure performance.

Sections 60.15 and 60.17 of 10 CFR Part 60 have been incorporated into the planning of the site characterization program. Consideration of the requirements has impacted the planning of the surface-based drilling program with regard to the extent of characterization within the repository block (i.e., number of exploratory boreholes), the drilling methods to be used (i.e., dry, wet, mist), the drilling depth of boreholes, the construction controls to be used, the sequence in which the holes are to be drilled, and the consistency of proposed locations with the repository design.

For the ESF design and planned operations, the requirements of these sections of 10 CFR Part 60 have been applied to the establishment of controls on selected operations (i.e., blasting and water use), the evaluation of the location and configuration of the shafts relative to long-term performance, and the integration of the ESF and repository layouts to ensure compatibility between the proposed exploration and the conceptual design of the repository. The specific sections of Section 8.4 in which the various criteria in 10 CFR 60.15 and 60.17 have been considered are identified in Table 8.4.1-1.

In the preceding discussion, the term "performance" is used in the sense of the ability of the repository system to meet the postclosure performance objectives identified by the NRC. Four postclosure performance objectives are identified in 10 CFR 60 Subpart E in 60.112 and 60.113. These post-closure performance objectives are summarized in Table 8.4.1-2, together with the location of the related discussion in Section 8.4. The discussions in Section 8.4.3 evaluate whether the site characterization activities are consistent with meeting the postclosure performance objectives. The post-closure performance objectives have impacted the planned characterization program and operations principally by providing constraints including such factors as the proposed construction methods, the controls to be placed on those methods, and the shaft locations.

Table 8.4.1-2. Postclosure performance objectives from 10 CFR Part 60 related to discussions in Section 8.4 (page 1 of 2)

| 10 CFR 60 Citation | Principal objectives | 8.4 Section |
|---|---|---|
| Subpart E | | |
| 60.112 | Overall system performance objective for the geologic repository after permanent closure (postclosure performance objectives) | 8.4.3.3.1 |
| | Select geologic setting and design engineered barrier system, and shafts, boreholes and their seals to assure that releases of radioactive material conform to Environmental Protection Agency standards for both anticipated and unanticipated processes and events | |
| 60.113 | Performance of particular barriers after permanent closure (postclosure performance objectives)<br>For anticipated processes and events | |
| | (a) (1) Substantially complete containment within waste package for 300-1000 years after closure (a)(1)(ii)(A) -- assuming anticipated processes and events | 8.4.3.3.2 |
| | Release rate from engineered barrier system after containment period shall not exceed one part in 100,000 per year of 1,000 year inventory (a)(1)(ii)(B) | 8.4.3.3.3 |

Table 8.4.1-2. Postclosure performance objectives from 10 CFR Part 60 related to discussions in Section 8.4 (page 2 of 2)

| 10 CFR 60 Citation | Principal objectives | 8.4 Section |
|---|---|---|
| | Geologic setting | |
| (a)(2) | Locate repository so that pre-waste-emplacement ground water travel time along fastest path of likely radionuclide travel from disturbed zone to accessible environment is at least 1,000 years | 8.4.3.3.4 |

In addition to the direct guidance for site characterization and the definition of the postclosure performance objectives, 10 CFR Part 60 provides other technical criteria in Subpart E. These include specific requirements to be placed on the repository facility to further ensure public health and safety during the postclosure phase. In those instances in which a direct linkage can be demonstrated, it is considered appropriate to evaluate the potential impacts of site characterization on the capability to ultimately comply with other selected requirements in Subpart E. The additional technical criteria from Subpart E considered in the evaluations in 8.4 are identified in Table 8.4.1-3. Note that several of the criteria presented in Subpart E do not appear in the list of those considered in Table 8.4.1-3. This is generally because those criteria are not viewed as being closely related to postclosure performance impacts of the site characterization program. In general, those sections of Subpart E that have not been addressed directly in Section 8.4 include 10 CFR 60.131 (general design criteria for the general repository operations area), 10 CFR 60.132 (additional design criteria for surface facilities), and portions of 10 CFR 60.133 (additional design criteria for underground facility), of 10 CFR 60.134 (design of seals for shafts and boreholes), and 10 CFR 60.135 (design criteria for the waste package).

The significance of the criteria in 10 CFR 60.133, 60.134, and 60.137 to the site characterization program has generally been to add some specificity to several of the impact evaluations. For example, specific evaluations of (1) the flexibility of the design to accommodate site-specific conditions encountered in construction, (2) the control of water and gas, (3) excavation methods and allocation of a dedicated testing area consistent with both site characterization and performance confirmation needs, and (4) postclosure sealing are among the items considered when determining if the characterization program is consistent with meeting these regulations. In particular, the length of time for which the shaft is designed to be usable is 100 years, consistent with the requirements for maintaining the option to retrieve the waste. Sections of 8.4 that describe the considerations relative to assuring consistency with meeting these parts of 10 CFR 60 are tabulated in Table 8.4.1-3.

As indicated, considerable attention has been paid to ensuring that the site characterization program is consistent with the requirements of 10 CFR 60. This attention has resulted in specific layouts of proposed characterization tests and in the adoption of appropriate construction controls.

The remainder of Section 8.4 is devoted to describing in more detail the characterization program, the planned operations, and how these operations have been evaluated to ensure that the program is consistent with meeting the regulations. Before proceeding with these discussions, however, the concepts of unsaturated zone flow and their application to Yucca Mountain will be discussed. These concepts are particularly important because an understanding of them is a prerequisite for understanding the potential impacts of testing activities on site integrity and because the unsaturated zone is the primary element that the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site.

Table 8.4.1-3. Technical criteria from 10 CFR Part 60 related to discussions in Section 8.4 (page 1 of 3)

| 10 CFR 60 Citation | Principal objectives | 8.4 Section |
|---|---|---|
| Subpart E | | |
| 60.133 | Additional design criteria for the underground facility | |
| | (a) General criteria for underground facility | |
| | (1) Orientations, geometry, layout, and depth of the underground facility and design of engineered barriers that are part of the underground facility shall contribute to containment and isolation | 8.4.2.3.3<br>8.4.2.3.4<br>8.4.3.3 |
| | (2) Design underground facility so that effects of credible disruptive events during operations, such as flooding, fires and explosions, will not spread through the facility | 8.4.2.3.3<br>8.4.2.3.4<br>8.4.3.2.4<br>8.4.3.3 |
| | (b) Flexibility of design | |
| | Design underground facility with sufficient flexibility to allow adjustments to accommodate site specific conditions | 8.4.2.3.6.4 |
| | (c) Retrieval of waste | |
| | Design underground facility to permit retrieval of waste in accordance with 60.111 | 8.4.2.3.6.3 |

Table 8.4.1-3. Technical criteria for 10 CFR Part 60 related to discussions in Section 8.4 (page 2 of 3)

| 10 CFR 60 Citation | Principal objectives | 8.4 Section |
|---|---|---|
| 60.133 (continued) | (d) Control of water and gas | |
| | Design of underground facility for control of water or gas intrusion | 8.4.2.3.3<br>8.4.2.3.4<br>8.4.3.3 |
| | (e) Underground openings | |
| | (1) Design underground openings so operations can be carried out safely and retrievability option maintained | 8.4.2.3.3<br>8.4.2.3.4<br>8.4.2.3.6.3 |
| | (2) Design underground openings to reduce potential for deleterious rock movement or fracturing of overlying or surrounding rock | 8.4.2.3 |
| | (f) Rock excavation | |
| | Design of underground facility to incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water to contact waste packages or radionuclide migration to the accessible environment | 8.4.2.3.3<br>8.4.3.3 |
| | (h) Engineered barriers | |
| | Design engineered barriers to assist geologic system in meeting postclosure performance objectives | 8.4.3.3.2<br>8.4.3.3.3 |

Table 8.4.1-3. Technical criteria for 10 CFR Part 60 related to discussions in Section 8.4 (page 3 of 3)

| 10 CFR 60 Citation | Principal objectives | 8.4 Section |
|---|---|---|
| 60.133 (continued) | (i) Thermal loads | |
| | Design underground facility to meet performance objectives considering predicted thermal and thermomechanical response of host rock, and surrounding strata, ground water system | 8.4.3.2.1.4<br>8.4.3.2.4 |
| 60.134 | Design of seals for shafts and boreholes<br>(a) General design criterion<br>Seals shall be designed so that following permanent closure they do not become pathways that compromise ability to meet performance objectives | 8.4.3.3.1<br>(8.3.3.1)<br>(8.3.3.2) |
| 60.137 | General repository operations area designed to permit implementation of performance confirmation program that meets requirements of subpart F | 8.4.2.3.6.2<br>8.4.2.3.6.4 |
| Subpart F | | |
| 60.140 | General requirements<br>(b) Timing<br>Performance confirmation will start during site characterization and continue until permanent closure | |
| | (d) Constraint<br>Not adversely affected ability of repository to meet performance objectives | |

## 8.4.1.3 Concepts of unsaturated-zone flow and their application to Yucca Mountain

### Introduction

Subsequent portions of this section present or make reference to analyses that address the impact of site characterization activities on waste isolation and containment or that evaluate the interaction among various tests or construction features. These analyses primarily consider the flow of fluids (liquid water and water vapor or other gases) in the vicinity of excavations (shafts, drifts, drillholes, or trenches) in the unsaturated zone at Yucca Mountain. An important requirement for understanding these analyses and the conclusions drawn from them is a review of some of the basic concepts of ground-water flow in the unsaturated zone. Of special importance for this section is an understanding of the effects of excavations including boreholes, shafts, and drifts on unsaturated rocks and the effects of fluids that might be introduced as the excavations are developed.

The evaluations of the ultimate performance of a repository at the Yucca Mountain site will be based on predictions of ground-water flow and radionuclide transport in the unsaturated zone. These predictions will consider both the hydrogeologic setting of the site, as derived from present information and from the site characterization program, and the credible disruptive classes that could extensively modify that hydrogeologic setting. In addition, these predictions consider the possible effects of both surface and subsurface site characterization activities on the performance of the repository. At this point in the program, preliminary evaluations can be made of the impacts of characterization activities by examining the specific effects of relatively small-scale excavations into the unsaturated zone. These preliminary evaluations must also consider the basic hydrogeologic setting and credible disruptive classes that apply to these excavations.

These evaluations of the impacts of site characterization excavations must address basic questions, including the following:

1. What effects on the moisture flow system are produced by the construction of an excavation or testing in the excavation in the unsaturated zone; i.e., does it introduce increased flux to the repository horizon or does it create a preferential pathway?

2. What effects are produced on the unsaturated-zone flow system by the existence of an excavation that is backfilled or sealed?

3. If fluids are introduced into these openings (by infiltration of surface water, by lateral moisture movement toward the excavation, or from construction fluids used during excavation) what is the expected effect on the flow system?

The remainder of this section will present information that supports some general hypotheses concerning moisture flow in the unsaturated zone that can be applied to the Yucca Mountain site. Supporting technical analyses are summarized in Section 8.4.3 and numerous activities that will evaluate or test these hypotheses are described in Section 8.3.1.2. The following

hypotheses are extracted from the set of hypotheses presented in Section 8.3.1.2 and are listed for discussion:

1. The rocks at the proposed repository horizon and the rocks above and directly below this horizon are unsaturated.

2. The flow system is approximately steady state, or responds very slowly to hydrologic perturbations.

3. Water tends to be held in rock-matrix pores and does not move readily into relatively large openings, such as large-aperture fractures, boreholes, and drifts; conversely, water tends to be imbibed into small openings (pores) from large openings (fractures).

4. Moisture flow in the unsaturated zone occurs both as liquid water and water vapor.

5. The hydraulic conductivity of an unsaturated rock mass is strongly affected by the degree of saturation and decreases with decreasing saturation.

These hypotheses concerning moisture flow in the unsaturated flow lead to the following preliminary conclusions about the impact of excavations in the unsaturated zone at Yucca Mountain:

1. Liquid-water flow occurs predominantly in the unsaturated rock matrix. Neither large-aperture fractures nor the excavations are expected to be conduits for water flow in the unsaturated zone under existing conditions. Fractures and excavations, however, must be examined as potential pathways for gas phase (including water vapor) and liquid water movement under conditions associated with the range of scenarios needed to assess total system performance.

2. Excavations will be backfilled during repository closure with material that has properties such that under expected conditions it will also be unsaturated. This backfill and other seal components will be designed to limit vapor flow and flow of surface water that might have access to these excavations. As a result of these designs, water entering the backfill would be expected to be imbibed into the rock matrix.

3. The limited quantities of liquids that are expected to be introduced into excavations during site characterization operations are expected to be dispersed into the available rock matrix pore space within reasonably short distances from the excavations; however, localized flow in fractures could result from injected liquid, although this flow also would be ultimately imbibed and dispersed within the rock matrix.

Concepts of flow

Current understanding of the hydrology of the unsaturated zone at Yucca Mountain is based on the knowledge of the physics of moisture flow in the unsaturated zone, preliminary data and analyses of Yucca Mountain properties

(Chapter 3 and Section 8.4.3.2.1), the understanding of the site geologic framework, and knowledge derived from physical analogs. This discussion focuses on the basic physics of flow and is a highly simplified introduction to a complex hydrologic system. A more detailed, technical discussion of fluid-flow conditions and processes in the unsaturated zone at Yucca Mountain is presented in Sections 3.6 and 3.9. Section 8.3.1.2 discusses alternative conceptual models, including hypotheses and uncertainties related to unsaturated fluid flow at Yucca Mountain.

The unsaturated zone is defined to be the rock mass and its contained fluids between the land surface and the water table. Within the unsaturated zone, most of the rock-matrix pores are not completely filled with water, (i.e., the rocks are unsaturated). The percentage of pore space filled with water is expressed as the degree of saturation. Saturation generally varies spatially, and from unit to unit. Water within the partially saturated pores of the unsaturated zone is held under tension, which, in effect, produces a net negative "pressure," or potential. In contrast, in the saturated zone the interconnected pores are completely filled with water, the water is under hydrostatic compression, and the pressure in the water-filled pores is positive. The boundary between the two zones defines the water table, which is that surface at which the liquid-water pressure is atmospheric. The position of the water table at a point is commonly identified by the level at which standing water occurs in an uncased borehole that penetrates the saturated zone.

The potential energy of water determines the state and movement of water. Water usually flows from regions of high potential energy to regions of lower potential energy in both the saturated and unsaturated zones. This energy-driven water flow moves to establish an equilibrium state within the system. When water reaches the state of equilibrium, defined as a condition of uniform or equal potential energy, there is no flow. The state of equilibrium in a natural system can be approached but probably never attained. The system may, however, approach a steady-state condition in which the net rate of inflow to the system is approximately equal to the net rate of outflow from the system. Under these conditions, local equilibrium would be established between and within small scale parts of the system, such as a fracture and the adjacent rock matrix.

In the unsaturated zone, the total water potential at a point is approximately equal to the sum of the gravitational potential energy and the matric potential. The gravitational potential energy is directly proportional to the height of the point above a reference datum. Because of the gravitational potential, the general direction of flow in the unsaturated zone is downward. The matric potential is the energy of the water within the pores resulting from the attraction of water molecules in the partially filled pores to the matrix enclosing the pore and to each other. Matric potential includes the energy of water due to surface tension in the pores (capillarity) and the water adsorbed on the matrix surfaces. Matric potential is inversely proportional to the size of the pore space (or other opening, such as a fracture aperture) that contains water. The resultant force due to gravitational potential energy and matric potential determines the specific direction that water flows; locally, this direction may be other than downward. Matric potential is frequently expressed as a suction, or as a negative pressure.

Because the matric potential is inversely proportional to the size of the opening containing water, unsaturated small pores imbibe water preferentially to large pores. Thus, in this relatively simplistic capillary-bundle theory, water tends to move from large pores into small pores until matric potential equilibrium between the large and small pores is reached. As a result, under unsaturated conditions, water generally does not flow from the matrix into large-aperture fractures or into open boreholes or drifts. Once local saturated or nearly saturated conditions are reached in the matrix, then such flow can occur. In reality, the conditions under which water flows in fractures depend on many factors, such as the relative size of the pores and fractures, the internal geometries of the fractures, the degree of fracture interconnection, and whether wetting or drying conditions are occurring, as well as the degree of saturation. These effects are documented in many analyses of unsaturated flow around openings (see, for example, Beven and Germann, 1982). Water stored within an unsaturated rock mass, therefore, would not be expected to move spontaneously into boreholes, drifts, shafts, waste-emplacement holes, or other openings whose diameters exceed the sizes of the pores. Movement into large openings requires additional external energy to initiate a transient change capable of causing such movement, such as increased infiltration or local heterogeneities and geometries that result in focused flow.

Under certain circumstances, water-vapor flow may significantly contribute to total water flow in the unsaturated zone. In most instances, water-vapor flow in the unsaturated zone at depths typical of the repository is by diffusion, which is a relatively slow process and, therefore, contributes only a small amount to the total water flow. When large amounts of air (which is nearly saturated with water vapor) circulate within or flow out of the unsaturated zone, then water-vapor flow may become much more substantial. Water-vapor flow may be greater near the land surface, especially if large openings, such as fractures, faults, boreholes, or shafts, occur in the unsaturated zone exposed to the surface where the effects of barometric air pressure changes are more pronounced (Weeks, 1987).

The concepts of liquid-water flow in unsaturated and fractured porous media can be illustrated with characteristic curves (Figure 8.4.1-1), which depict saturation as a function of matric potential for both a fracture and the adjacent rock matrix. When a porous material is saturated, the matric potential is zero. When the saturation decreases, water leaves the largest pores first, decreasing the corresponding value of matric potential. The smaller pores that preferentially hold the water retain water at much smaller matric potentials (more negative pressure). Water-characteristic curves can be empirically or theoretically derived; their shape is related to the distribution of different pore sizes in the matrix. In general, at a particular saturation, the matrix with smaller pores has a smaller matric potential (more negative) than a matrix with larger pores.

Under equilibrium conditions, the water potential in a fracture and the water potential in the matrix immediately adjacent to the fractures are equal. If a fracture is thought of as a large pore, then a fracture at equilibrium with a matrix that is unsaturated contains very little water if, for example, as shown in Figure 8.4.1-1, the matrix potential is -100 bars, corresponding to the saturation value of 0.3 for the matrix. In this

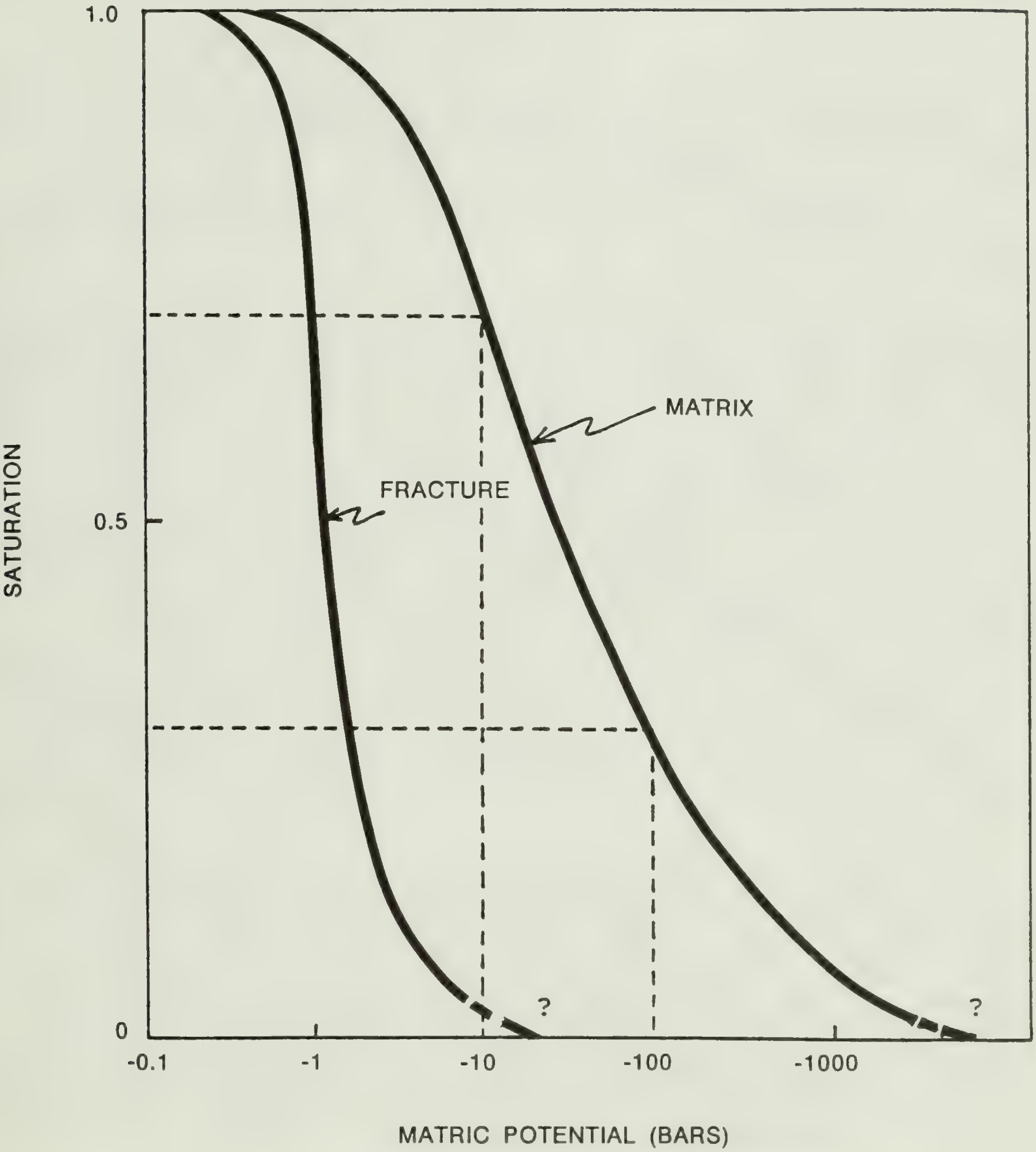


**Figure 8.4.1-1.** Hypothetical matric potential verus saturation for fractures and rock matrix; ? indicates uncertainty.

example, measurable amounts of water do not move into the fractures until the matric potential approaches -10 bars (matrix saturation of 0.7).

The pore-size distribution and the tortuous geometry of the flow path fixes the upper limit of hydraulic conductivity (the measure of the ability to transmit fluids) in the matrix. The highest conductivity for flow through the matrix is the saturated hydraulic conductivity. The hydraulic conductivity of the matrix is reduced if the saturation is less than 1.0 (Figure 8.4.1-2). This reduction in hydraulic conductivity with decreasing saturation is one of the major differences between saturated and unsaturated water flow.

The example in Figure 8.4.1-2 is provided to show the hypothetical relationship between hydraulic conductivity in the matrix and fractures over a wide range of matric potentials. In this example, the saturated hydraulic conductivity for the matrix is approximately $5 \times 10^{-6}$m/s. If the matric potential were lowered to -10 bars (saturation of 0.7, Figure 8.4.1-1), then the unsaturated hydraulic conductivity would be $1 \times 10^{-6}$m/s, a factor of 5 reduction in hydraulic conductivity. If, in this hypothetical case, the fracture and the matrix were at the same matric potential (-10 bars), the conductivity of the fracture would be less than $1 \times 10^{-9}$m/s, practically nonexistent compared with that of the matrix. Water flow in fractures would make an equivalent contribution to the overall flow rate when the water potential is approximately -0.3 bars (near saturation for the matrix), because until that point is reached, the hydraulic conductivity of the fractures is much less than that of the matrix. If water potentials in the matrix exceed this value, flow in the fractures would be expected to dominate the system because the hydraulic conductivity of the fracture would be substantially greater than that of the matrix. The hydraulic conductivity would be limited only by the saturated hydraulic conductivity of the fracture (approximately $5 \times 10^{-5}$m/s).

The degree of matrix saturation at which a fracture begins contributing to flow depends on the effective saturation-matric potential curves for both the matrix and fractures. Generally, the matrix must attain a high degree of saturation before water movement occurs along fractures. Water may move across a fracture at asperities, which are points of contact between the two walls of a fracture. Because heterogeneities in values for the matrix properties (e.g., characteristic curves, saturated conductivities, porosities) and the state variables (such as saturation) commonly occur in nature, water movement in fractures may occur at sporadic locations where local saturations in the matrix material are high. While this sporadic flow in fractures may occur, the predominant flow in the unsaturated zone probably is through the matrix.

At steady-state conditions, the net moisture inflow is approximately equal to the net moisture outflow. This condition does not necessarily mean that water has ceased to flow, but rather that the system's state variables (such as saturation) are not changing or are changing only very slowly. Thus, at any depth within the unsaturated zone, the rate of water movement (either liquid or vapor) into a region plus any changes in state (liquid to vapor or vapor to liquid) are balanced in such a way that there is no net change in the conditions within the region (i.e., the amount and distribution of liquid water, water vapor, and air remain constant within the pore space).

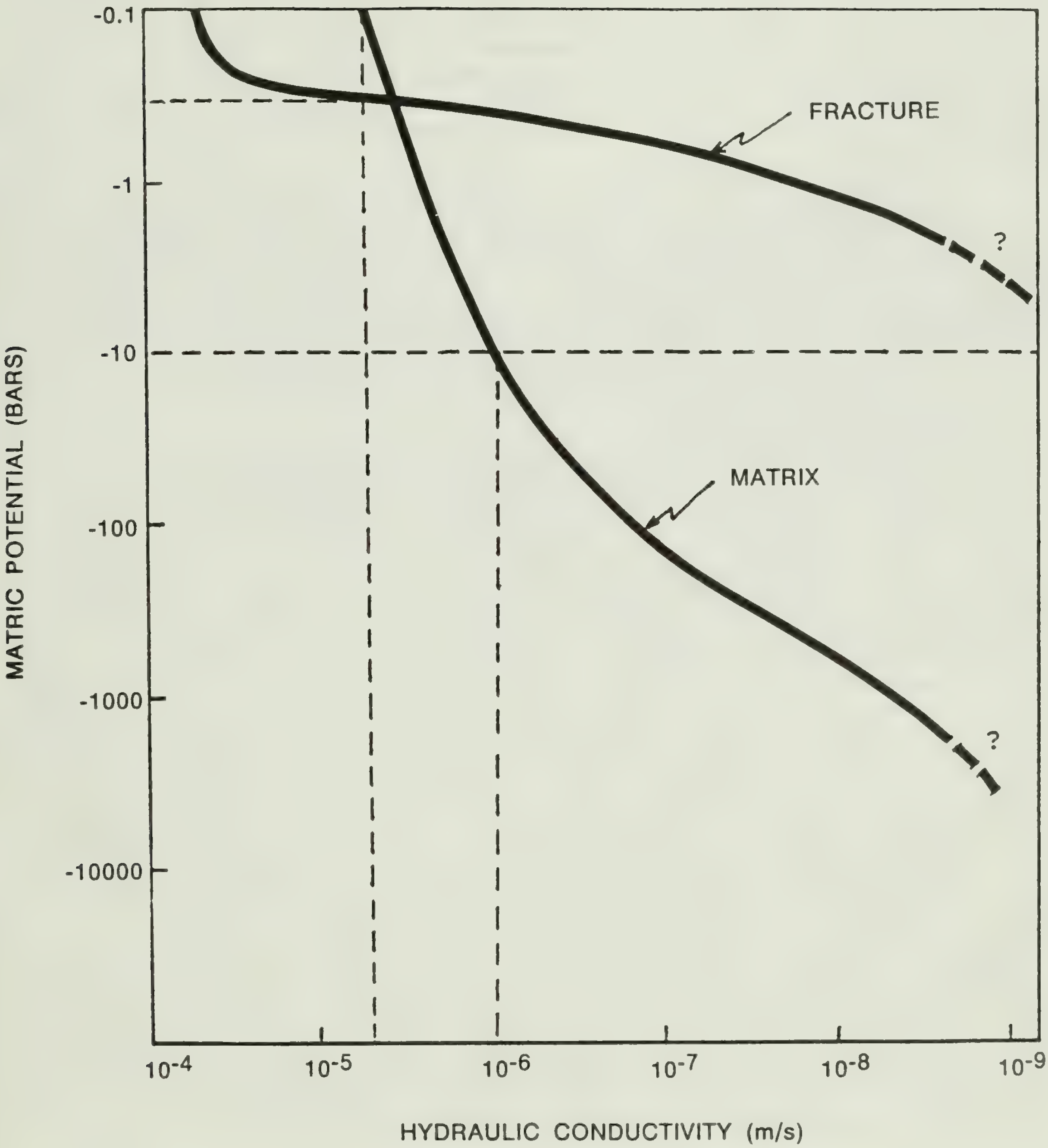


**Figure 8.4.1-2.** Hypothetical hydraulic conductivity versus matric potential curve for fracture and rock matrix; ? indicates uncertainty.

Under steady-state conditions, the hydrologic conditions within the unsaturated zone are likely to change only very slowly over time. Steady-state conditions do not necessarily preclude other hypotheses, such as lateral water movement or vapor movement. Transients can occur locally, even under generally steady-state flow. Transients entail a short-time change in the state variables (i.e., saturation) within a region. After the transient flow ceases, the system will recover and steady-state flow will tend to be reestablished.

Perched water, ponding, or locally saturated conditions can occur at permeability contrasts. These include geologic contacts where water is moving from a rock with small pores (i.e., one with low saturated hydraulic conductivity) to one with large pores (i.e., one with a high saturated hydraulic conductivity), and where the geometry and structure of the rock heterogeneities and the percolation rates are appropriate.

Relation to Yucca Mountain

Geologically, Yucca Mountain is composed of a layered sequence of volcanic rocks consisting of variably indurated (or welded) volcanic ash. The hydrologic properties of these rocks depend largely on the degree of welding. In particular, the saturated hydraulic conductivity of the matrix of these rocks decreases appreciably with increasing degree of welding. Because of these variations among the properties of the rocks composing the unsaturated zone at Yucca Mountain, the rocks have been divided into a vertical sequence of five principal hydrogeologic units. The central crest of Yucca Mountain above the repository is capped by the Tiva Canyon welded unit (TCw), which has a low rock-matrix saturated hydraulic conductivity but tends to be highly fractured. Underlying the TCw is the Paintbrush nonwelded unit (PTn), which is characterized by a relatively high saturated hydraulic conductivity and few fractures. Below the PTn unit is the thick (about 300 m) Topopah Spring welded unit, which, in the discussion that follows, is subdivided into an upper unit designated TSw1 and a lower unit designated TSw2. The lower TSw2 subunit includes the repository horizon. In general both the TSw1 and TSw2 units are welded tuffs that have a relatively low saturated hydrologic conductivity but tend to be highly fractured. The Calico Hills nonwelded unit (CHnw) underlies the TSw2 unit and is situated between the TSw2 unit and the underlying water table. Within much of its areal extent beneath the repository horizon, the CHnw unit is characterized by a low hydraulic conductivity, relatively few fractures, and the presence of minerals (zeolites) that are capable of retarding radionuclide migration. Consequently, the CHnw unit is considered the principal natural barrier for radionuclide transport in the unsaturated zone at the site.

The assessments of site performance, with respect to the current understanding of the hydrologic conditions and important processes at Yucca Mountain, are based on the hypothesis that the rock mass above the water table is unsaturated, in a near-steady-state flow condition, and that the steady-state moisture flux values are low enough that matrix flow dominates the process. Additionally, it is presumed that large-scale stratigraphic features (layering and material contrasts) in conjunction with the imbibition potential of the near-surface unsaturated rocks reduce the likelihood that extremes in climatic fluctuations result in deep percolation events. Although available unsaturated-zone data are very sparse, these data and

analyses based on these data are consistent with these hypotheses. More importantly, the limited data and analyses are not consistent with the presumption that the site is near saturation over the entire profile, nor with the presumption that highly transient flow conditions exist or have the potential to exist over short time periods. Current understanding of unsaturated-zone flow phenomena leads to the conclusion that water does not spontaneously move from the small pores of the unsaturated porous rock matrix within the unsaturated zone at Yucca Mountain into larger openings (e.g., shafts, boreholes, drifts, or fractures). Flow would be expected to be constrained primarily to the matrix except for, as noted earlier, local perturbations resulting from local conditions related to geometry and heterogeneity. On the basis of certain assumptions, hypotheses, and present understanding, the analyses lead to a prediction that ground-water travel times are very long and the system is sufficiently robust to accommodate small perturbations of ambient conditions. The appropriateness of these hypotheses will be extensively investigated during site characterization to determine if they are correct, or if alternative hypotheses are more appropriate. A direct way of determining the validity of these hypotheses will be an examination of the drifts underground within the ESF to identify the extent to which flow in fractures occurs and the degree of saturation of the matrix tuff around those fractures.

*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

## *Volume VIII, Part B*

*Chapter 8, Section 8.4.2, Description and Location of Characterization Operation*

*December 1988*

*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

## 8.4.2 DESCRIPTION AND LOCATION OF CHARACTERIZATION OPERATIONS

Section 8.4.2 addresses the adequacy of the planned surface and subsurface activities for characterizing the range of conditions and processes important to performance and design at the Yucca Mountain site. The section also evaluates whether construction or operation of facilities or the conduct of tests at the site is likely to adversely influence the results of site characterization activities.

The performance and design requirements of 10 CFR 60 Subpart E were reviewed in Section 8.4.1. The DOE has translated these requirements into an issues hierarchy, as described in Section 8.2. Performance allocation was then performed on an issue-by-issue basis to establish the testing needs for resolving each issue. Section 8.4.2.1 reviews the postclosure and preclosure data needs that were identified in Section 8.3 to satisfy performance and design issues. This section also discusses the testing methods available for obtaining these data. Based on these considerations, the planned site characterization activities are discussed, and an evaluation is made of the representativeness of the data being collected. Sections 8.4.2.2 and 8.4.2.3 assess the likelihood of test-to-test and construction-to-test interference in the surface-based and subsurface-based activities. Each of the exploratory shaft facility (ESF) tests is discussed, along with layout constraints imposed on the design, construction, or operation of the facility. The zone of influence is estimated for each test, and the potential for construction and operation interference is evaluated.

### 8.4.2.1 Rationale for planned testing

The purpose of this section is to present information that establishes the adequacy of the proposed site characterization program for estimating the ranges of conditions and processes that are needed to support repository design and to evaluate the performance of the Yucca Mountain site. Based on current understanding, data from surface-based testing, in conjunction with testing in the proposed ESF, is expected to be adequate for performance assessment. This section provides the rationale for this statement by discussing (1) the principal data needed for preclosure and postclosure design and performance evaluation; (2) the various methods available for obtaining these data; (3) the activities to be conducted during site characterization, and the major considerations for choosing them; and (4) the representativeness of the data to be obtained, focusing on the relation between surface-based testing and testing in the ESF, the location of the ESF, and statistical considerations.

Before site characterization begins, only a limited amount of regional and site-specific information will be available, which will limit the following planning and analysis activities:

1. Evaluation of repository and engineered barrier designs.

2. Evaluation of the representativeness of data collected in the planned characterization activities.

3. Comparative evaluation of potential benefits of planned activities versus risks to site performance.

4. Evaluation of the potential for interferences between tests and between construction and tests that could affect data quality.

5. Evaluation of the adequacy of planned activities with respect to measurement type, range, accuracy, location, etc.

These are important constraints because they require flexible, incremental plans that can be advanced or modified as new information becomes available. As more is learned about the system through observation and testing, ongoing or planned characterization activities will be reviewed to ensure that they are appropriately focused. The bases for evaluating and adjusting the activities during site characterization are as follows:

1. The early results from site characterization activities will be used to identify what further testing may be necessary.

2. Intermediate stages of characterization will refine the descriptions of site conditions and the significant processes involved, concentrating on reducing the uncertainty in performance evaluations and obtaining information for model validation.

3. Later stages will be primarily involved in acquiring information for the performance confirmation program for completing model validation.

Changes in planned site characterization activities or the inclusion of new site characterization activities will be reported in the semiannual progress reports.

The representativeness of data from the planned site-characterization activities is evaluated in this section (1) by describing the data needed for performance and design analyses and (2) by considering the alternative methods for obtaining this information, as well as the rationale for selecting the proposed test methods. The data needs were identified in the performance-allocation process described in Section 8.1 and are associated with quantifiable performance measures and parameters for assessing the performance and design issues. Because performance measures are often described in terms that cannot be compared directly with observations, they must be evaluated using models and parameters derived from observations. In other instances, the large time scales associated with a process and the spatial variability of data preclude an approach to issue resolution based only on observation.

Another consideration in developing site characterization activities is the need to evaluate the hypotheses that constitute alternative conceptual models. These hypotheses concern physical domain, driving processes, boundary conditions, geometry, and system responses that are important to performance. By testing the validity of competing hypotheses, the site characterization activities reduce the uncertainty in the performance-assessment predictions. The various hypotheses and the activities planned to

test alternatives are discussed in general in Section 8.3.1.1 and, specifically in various site programs in Section 8.3.1.

Sections 8.4.2.1.1 and 8.4.2.1.2 present the principal data needed to evaluate postclosure performance and preclosure design requirements. Section 8.4.2.1.3 discusses the various methods currently available for obtaining this information, which is followed by a description in Section 8.4.2.1.4 of what methods have been included in the planned testing program and the bases for these decisions. Section 8.4.2.1.5 evaluates data representativeness based on the extent and location of planned tests and other statistical considerations.

### 8.4.2.1.1 Principal data needed for postclosure performance evaluations

The following is a summary discussion of the principal links between the issues hierarchy and the data needs. Table 8.4.2-1 summarizes the principal postclosure data needs (including those for pre-waste-emplacement ground-water travel time), and shows the related performance measures or other criteria, information needs, and design and performance issues. This table presents only those information needs, performance measures, or other criteria that require site data; Sections 8.2 and 8.3.5 provide a more complete discussion of issue resolution. The table can be used to relate the data needs to the requirements set forth in the various regulations by reviewing the issues hierarchy discussion in Section 8.2.1.2.

In the following discussion, principal data needs are grouped by major areas of evaluation; specific data needs are shown in performance-allocation tables in Section 8.3.5. The parameters included in those tables, and the data needs discussed below, generally are those that are directly needed for performance evaluations. Those parameters generally are supported by a great variety of less-specific data that are needed to develop the performance parameters and to build confidence in the values for those parameters.

#### Flow and transport data needs

Because of the reliance being placed on the unsaturated zone for waste isolation performance, principal data needed for flow and transport aspects of postclosure performance evaluation are from the unsaturated zone. Included is the consideration of pre-waste-emplacement ground-water travel time. The data needs derive in part from a need to test concepts of fluid flow in the unsaturated zone. To model flow and transport in the unsaturated zone with an acceptable level of uncertainty in the predictions, additional unsaturated-zone information is needed in the following areas: (1) hydrologic conditions and processes, including those for the Calico Hills unit; (2) geochemical conditions and processes; (3) geomechanical and thermal influence on the hydrologic conditions and processes; (4) the magnitude of surface infiltration and processes controlling flux; (5) gaseous movement and the pneumatic conductivity in the repository block; (6) stability of the water table; and (7) water chemistry.

Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 1 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | | PERFORMANCE ISSUES | |
| Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13? | 1.1.1--Site information needed to calculate releases to the accessible environment | Scenario evaluations; need probability distributions for events constituting scenarios<br>Linked to virtually every other performance issue<br>Reliance on ground-water travel time (GWTT) in the UZ<br>Geochemical retardation in the UZ as backup<br>Saturated zone processes as backup | Data for unsaturated zone (UZ) flow and transport models[e]<br>Data on the scale dependence of rock mass under experimental conditions<br>Data on the waste package environment<br>Site data for geologic, hydrological, and geochemical/geophysical models[f]<br>Data for thermal/mechanical/hydrologic and physical-properties models[f]<br>Data to evaluate alternative conceptual models of postclosure performance |
| Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15? | 1.2.1--Determination of doses to the public in the accessible environment through liquid pathways<br>1.2.2--Determination of doses to the public in the accessible environment through gaseous pathway | For ground-water transport of nuclides, rely on GWTT in 1,000 yr<br>For gaseous transport, rely on low inventory, gaseous diffusion, and (possibly) chemical immobilization of carbon-14 in the UZ | Data for UZ flow and transport model[e] |
| Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16? | 1.3.1--Determination whether any Class 1 or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary<br>1.3.2--Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 yr after disposal could exceed the limits established in 40 CFR 191.16. | Show three aquifers (valley fill, tuff, lower carbonate) are not "special sources" as defined (survey local population distribution and ground-water use)<br>If necessary, evaluate contamination within 1,000 yr of waste emplacement using an approach similar to Issue 1.1, and relying on GWTT in the UZ | Data for UZ flow and transport models[e] |
| Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113? | 1.4.3--Scenarios and models need to predict the rate of degradation of the container material<br>1.4.4--Estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of the failure rate of the container as a function of time | Substantially complete containment; need additional data for site specific definition<br>Current definition calls for analysis of breaching scenarios for 1,000 yr, data on quantity and quality of water to contact container during containment period | Bounding conditions for UZ flow and transport model[e]<br>Data on the waste package environment |

Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 2 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| PERFORMANCE ISSUES (continued) | | | |
| Issue 1.5: Will the waste package repository engineered barrier system meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113? | 1.5.3--Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system<br>1.5.4--Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events<br>1.5.5--Determination of the amount of radionuclides leaving the near-field environment of the waste package | Engineered barrier system (EBS) requires definition; EBS boundary currently taken at surface of underground openings; EBS may control how ground water contacts waste; dependence on design | Data for UZ flow and transport model[e]<br>Data on waste package environment for times between 1,000 and 10,000 years |
| Issue 1.6: Will the site meet the performance objective for pre-waste-emplacement GWTT as required by 10 CFR 60.113? | 1.6.1--Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the GWTT along the path<br>1.6.5--Boundary of the disturbed zone | Definition of disturbed zone; evaluate appropriate calculational model(s) for flow system relying on site data from surface boreholes and the exploratory shaft facility (ESF)<br>Identify fastest path from calculational models | Data for UZ flow and transport model[e]; GWTT under nominal conditions<br>Data on in situ hydrologic responses of the rock mass under experimental conditions<br>Data on the scale dependence of rock mass characteristics |
| Issue 1.7: Will the performance-confirmation program meet the requirements of 10 CFR 60.137? | To be determined | Details of program depend on content of license application, and therefore on information obtained during site characterization<br>Candidate tests have been identified that begin during site characterization; See Table 8.3.5.16-1 | Area within ESF reserved as preliminary accommodation |
| Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122? | None identified | Resolution similar to Issue 1.1, but may rely more on expert judgment<br>Results should match Issue 1.1, and bounds on site studies (i.e., identification of major performance parameters) from Issue 1.1 should apply<br>Favorable and potentially adverse conditions; investigate favorable conditions only to the extent such conditions could lend confidence to demonstration of compliance, and compensate, if necessary, for potentially adverse conditions | Data for UZ flow and transport model[e]<br>Data on the waste package environment<br>Data to evaluate alternative models of postclosure performance |

Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 3 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | | PERFORMANCE ISSUES (continued) | |
| Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; and (b) can the comparative evaluation required by 10 CFR 960.3-1-5 be made?[g] | None identified | Depends on resolution of Issues 1.1 through 1.6, and 1.8 (since the Department of Energy guidelines reference Nuclear Regulatory Commision performance objectives)<br>Also requires erosion data from site studies | Data for UZ flow and transport model[e]<br>Data on the scale dependence of rock mass characteristics<br>Site data for geologic, hydrologic, and geochemical/physical models[f] |
| | | DESIGN ISSUES | |
| Issue 1.10: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135, and (b) provide information for the resolution of the performance issues? | 1.10.4--Postemplacement near-field environment | Rock load on waste container; temperature vs. time for container environment quantity and quality of water in contact; information on tectonic processes (breaching, igneous intrusion, or eruption)<br>Depends on repository design and EBS design and performance | Data needed to model the waste package environment |
| Issue 1.11: Have the characteristics and configurations of the repository and repository engineered barriers been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.133 and (b) provide information for the resolution of the performance issues? | 1.11.1--Site characterization information needed for design | Data on stress, fracturing, etc., affecting repository layout, orientation<br>Location and characterization of faults, water inflow conditions, ground conditions<br>Data to support controls on water use chemical changes with respect to postclosure performance<br>Data needed to define and control excavation-induced permeability changes<br>Data to support thermal loading consistent with performance | Data on geomechanical rock mass characteristics<br>Data for thermal/mechanical/hydrologic and physical properties models[f] |

Table 8.4.2-1. Principal site data needed for postclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 4 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | | DESIGN ISSUES (continued) | |
| Issue 1.12: Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues? | 1.12.1--Site, waste package, and underground facility information needed for design of seals and their placement methods<br>1.12.2--Materials and characteristics of seals for shafts, drifts, and boreholes<br>1.12.3--Placement method for seals for shafts, drifts, and boreholes<br>1.12.4--Reference design of seals for shafts, drifts, and boreholes | Data on hydrology of sealing environment<br>Data on nominal expected stress and temeprature conditions<br>Data on geochemical, hydrochemical, and seismic conditions with respect to seals performance<br>Hydrologic characterization of faults and fault zones | Data on the scale dependence of rock mass characteristics<br>Data on the in situ hydrologic responses of the rock mass under experimental condition<br>Site data for geologic, hydrologic, and geochemical/geophysical models |

[a]Issues 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.9, 1.10, 1.11, and 1.12 and their respective information needs are given in Sections 8.3.5.13, 8.3.5.14, 8.3.5.15, 8.3.5.9, 8.3.5.10, 8.3.5.12, 8.3.5.18, 8.3.4.2, 8.3.2.2, and 8.3.3.2, respectively.

[b]Extracted from Table 8.2-2.

[c]From performance allocation discussed in Section 8.2.2.1.

[d]This column presents generalized descriptions of principal site data needed, for purposes of discussion in Section 8.4.2.1.

[e]UZ flow and transport model used to refer to predictive model of gaseous and liquid movement, and the resulting movement of radionuclides, under nominal and disturbed conditions, in the rock mass between the surface and the water table; emphasis is on liquid movement between the repository and water table, gaseous efflux from the repository, and natural infiltration along pathways such as fault zones.

[f]The models referred to are descriptive models described in the issue resolution strategies for hydrology (8.3.1.2, 8.3.1.2.2.8, and 8.3.1.2.2.9) geochemistry (8.3.1.3 and 8.3.1.3.7) and rock characteristics (8.3.1.4, 8.3.1.4.2.3.1, and 8.3.1.4.3.2.1).

[g]Given the passage of the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987), such comparisons are no longer required, although the evaluation will still be performed.

Because the saturated zone has been assigned a role of backup barrier for flow and transport, less emphasis is being placed on data needs for this component of the flow system. Nonetheless, to assess flow and transport characteristics of this system, data needs include hydrologic and geochemical conditions and processes, and hydrochemistry. Furthermore, saturated-zone conditions influence flow paths and rates in the unsaturated zone, principally by the position of the water table. As a result, data are needed on factors that affect the position of the water table, including the influences of geologic structure and lithology, climate, and tectonics. Thus, data are needed on rock characteristics, present and paleoclimates, paleohydrology, and current tectonic processes and stress conditions as they affect hydrology. The location and condition of faults within the repository site are also important data needs related to flow and transport, because they represent potential pathways to the accessible environment.

Waste package environment data needs

Information on temperature, stress state, moisture, and chemistry in the near-field environment of the waste package are needed to model the postclosure performance of the waste package and engineered barrier system, and to address the criteria of 10 CFR Part 60.135. Specific areas where data are needed include (1) ambient temperature and stress state in the repository horizon; (2) the hydrologic and geochemical conditions of the rock mass in the near-field; and (3) the heat-transfer processes and the influence of temperature variations on moisture migration, geochemistry, hydrochemistry, and thermomechanical processes.

Postclosure tectonics data needs

Data on the nature and condition of faults in and around the repository block are important for evaluating several of the scenarios for performance assessment related to radionuclide transport. Needed information includes (1) the geometry and condition (hydrologic, mechanical, and geochemical) of local faults; (2) the regional stress state; (3) nature and past history of faulting in the vicinity of the site; (4) the history of volcanism, potential eruptive and intrusive processes, and inferred future activity; and (5) the relation between tectonic processes and hydrology. These data are required for assessing various disruptive scenarios and their impact on the long-term performance of the site and the engineered barriers.

Resource evaluation data needs

The location, extent, value, and probability of occurrence of mineral resources at the site are needed to evaluate the likelihood of human intrusion. Similar information for natural gas resources is needed, particularly in the deeper rock formations of Paleozoic age.

Spatial variability of properties and conditions

Because rock is seldom homogeneous, the variability of the geologic, hydrologic, geochemical, mechanical, and thermal properties and conditions within the repository block needs to be characterized. Spatial variability within the site is a major source of modeling uncertainty, and the confidence

in the performance predictions will be improved by accounting for the variability of those parameters that significantly affect the output from an analysis.

Summary of postclosure information needs

The data needs for site characterization important for postclosure performance assessment were identified in the performance allocation process. In general, the data needs are related to the hydrologic, geologic, geochemical, mechanical, and thermal properties and processes relevant to the flow of water and the transport of radionuclides; waste package environment; tectonic activities; resource evaluation; and the spatial variability of the data.

### 8.4.2.1.2 Principal data needed for preclosure performance evaluations and design

Site characterization data are needed to support analyses related to meeting the two preclosure performance objectives (radiological safety and retrievability), to meeting 10 CFR 60.111(a) and (b), and to supporting and evaluating the repository design, including nonradiological health and safety concerns. The data needed by each of the preclosure performance and design issues (Section 8.2.2) are detailed in the performance allocation tables in Sections 8.3.2, 8.3.4, and 8.3.5. The principal types of site data needed for these issues are identified in Table 8.4.2-2. These data are grouped below relative to the support for surface and underground facilities design.

Surface facilities design data needs

The site information needed to design the repository surface facilities can be summarized into four categories: geologic information, meteorological and surface hydrologic information, site geometry, and surface soil properties. Many of these needs are specific to proposed locations of the surface facilities, as summarized in the following:

1. Geologic information needed includes location and characteristics of features, such as faults, and other data necessary to determine the probability, magnitude, and effects of seismic and volcanic events.

2. Meteorological and surface hydrologic information is needed to estimate flood potential and magnitude for design of area drainage; to set the values for tornado and wind loads on structures; to provide design values for heating, air conditioning, and ventilation systems; and to provide input to analyses of dispersion of potential radioactive releases for the assessment of worker and public radiological safety.

3. The geometry of the surface of the site is needed in conjunction with the meteorological information to estimate areas of potential flood inundation and to select favorable locations for surface facilities, including roads, buildings, and portals for underground access.

Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 1 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | PERFORMANCE ISSUES | | |
| Issue 2.1: During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111, 40 CFR 191 Subpart A, and 10 CFR Part 20? | 2.1.1--Site and design information needed to assess preclosure radiological safety | Characterization of dilution, transportation bioaccumulation of radionuclides in rivers, streams, foodstuffs<br>Characterization of atmospheric transport by wind and other convection mechanisms, including dispersion and diffusion | Meteorological and radiological monitoring<br>Surface hydrology information (runoff, streamflow) |
| Issue 2.2: Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations as required by 10 CFR 60.111 and 10 CFR Part 20? | 2.2.1--Determination of radiation environment in surface and subsurface facilities due to natural and man-made radioactivity | Characterization of atmospheric transport dispersion and diffusion within the site boundaries<br>Characterization of radiation attenuation by the host rock<br>Characterization of naturally occurring radionuclide radiation levels from miscellaneous sources, e.g., testing | Data on meteorological and radiological conditions<br>Compositional data including radon emanation rates and radiation shielding characteristics of the host rock |
| Issue 2.3: Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values? | 2.3.1--Determination of credible accident sequences and their respective frequencies applicable to to the repository<br>2.3.2--Determination of the predicted releases of radioactive material, and projected public and worker exposures, and exposure conditions under accident conditions, and that these meet applicable requirements | Frequency and consequences of initiating events caused by natural or site-related phenomena<br>Characterization of atmospheric transport characteristics at the site, including long-term environmental dispersion, dilution, diffusion, and bioaccumulation processes | Data on tectonic, volcanic, and meteorologic, or other hazards |
| Issue 2.4: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111? | 2.4.1--Site and design data required to support retrieval | Shielding characteristics of the host rock (see Issue 4.1)<br>Data on rockfall, emplacement borehole liner curvature, and liner lifetime in retrieval period | See data required by Issue 4.4 |

Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 2 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | PERFORMANCE ISSUES (continued) | | |
| Issue 2.5: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations? | Needed information taken from other preclosure issues | Uses information from Issues 2.1 and 2.2 | |
| Issue 4.1: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics | Needed information taken from other preclosure issues | Uses information from Issues 4.2, 4.3, and 4.4 | |
| | DESIGN ISSUES | | |
| Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues? | 2.6.1--Design information needed to comply with preclosure criteria from 10 CFR 60.135(b) for materials, handling, and identification of waste packages<br>2.6.2--Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms | Strategy combined with Issue 1.10<br>No site characterization data have been identified | |
| Issue 2.7: Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133 and (b) provide information for the resolution of the performance issues? | 2.7.1--Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to radiological protection have been met<br>2.7.2--Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design and protection of structures, systems, and components important to safety have been met | Identification of design-basis accidents, and site characterization data that can be used in support of design features in enhancing radiological safety | Data on spatial distribution of site characteristics, for geologic/geophysical, and hydrologic models[e]<br>Data on tectonic, volcanic, and meteorologic hazards<br>Data on geomechanical rock mass characteristics |

Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 3 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | DESIGN ISSUES (continued) | | |
| Issue 2.7 (continued) | 2.7.3--Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to criticality control have been met | | |
| Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues? | 4.2.1--Site and performance assessment information needed for design | Characterization of the properties and geometry of host rock, which control overbreak, blast-induced fracture, opening closure (supported), rock movement, rock fall, ramp grades, opening size, ventilation leakage, ventilation pressure drop, dust suppression, air quality, host rock temperature during retrieval, air quality, air cooling capacity, seismic activity | Principal needs taken from Issue 4.4 below |
| Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues? | Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package | Related to site data only through waste package performance issues | |
| Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues? | Site and performance assessment information needed for design | Location of surface facilities important to safety with respect to active geologic structures; characterization of potential for ground motion, and potential for volcanic eruption and ash fall<br>Location of surface facilities with respect to foundations (especially facilities important to safety), retaining walls, slopes, hydraulic conditions, soil stability<br>Location of underground facilities with respect to faults, potential faulting, potential volcanic activity, ground motion | Geological and meteorological information, site geometry, and subsurface soil properties in vicinity of surface facilities<br>Site geological information, site geometry, mechanical and physical properties of candidate horizon, rock shielding and radon emanation characteristics, site hydrological data, and site meteorological data |
| | | Characterization of host rock area and thickness with adequate overburden, and physical properties, for repository construction<br>Characterization of host rock properties for evaluations of nonradiological health and safety | |

Table 8.4.2-2. Principal site data needed for preclosure performance evaluation related to the information needs from the issues hierarchy requiring that data[a] (page 4 of 4)

| Issues | Information need[b] | Performance measure or other criteria[c] | Principal site data needed[d] |
|---|---|---|---|
| | DESIGN ISSUES (continued) | | |
| Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?[f] | 4.5.1--Estimate the costs of the reference and alternative waste packages<br>4.5.2--Estimate the costs of the reference and alternative repository designs<br>4.5.3--Estimate the life cycle costs of the reference and alternative total system design | Related to site data only insofar as information obtained during characterization may impact total cost estimate, through analyses performed for other issues | |

[a]Issues 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 4.1, 4.2, 4.3, and 4.4 and their respective information needs are given in Sections 8.3.5.3, 8.3.5.4, 8.3.5.5, 8.3.5.2, 8.3.5.6, 8.3.4.3, 8.3.2.3, 8.3.5.7, 8.3.2.4, 8.3.4.4, and 8.3.2.5.

[b]Extracted from Table 8.2-2.

[c]From performance allocation discussed in Section 8.3.5.

[d]This column presents generalized descriptions of principal site data needed, for purposes of discussion in Section 8.4.2.1.

[e]The models referred to are descriptive models described in the issue resolution strategies for hydrology (8.3.1.2, 8.3.1.2.2.9, and 8.3.1.2.2.10), geochemistry (8.3.1.3 and 8.3.1.3.7), and rock characteristics (8.3.1.4 and 8.3.1.4.2.3.1).

[f]Resolution of Issue 4.5 is not required as the Yucca Mountain site is the only site under consideration for development as a repository as designated by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987).

4. Soil properties, including both physical and mechanical properties, are needed to ensure that soil is not subject to excessive alteration as a result of wetting or to unacceptable rates of erosion. Mechanical properties of the surface soils are needed for foundation design and to predict the mitigation of seismic inputs to facilities important to safety.

Data needed for underground facility design

The site information needed to design the underground facilities (Tables 8.3.2.5-2 through 8.3.2.5-12) can be summarized into five basic categories: site geology, site geometry (surface topography, and the location, orientation, and extent of the candidate horizon), mechanical and physical properties of the host rock, site hydrology, and site meteorology. The information needed for these categories is described by the following:

1. Site geologic information, such as location and characteristics of physical structures such as faults, is needed to locate the subsurface facilities and to assess the magnitude and potential for occurrence of loading produced by seismic events.

2. Site geometry, including topography and the location, orientation, and extent of the candidate horizon, is needed to ensure that sufficient area is available for the required quantity of waste, to locate the repository in compliance with requirements for overburden and location relative to the water table, to establish roadway and drainage grades in the access ramps and underground openings, to set the elevation of the repository within a host-rock interval where physical and mechanical properties of the host rock are adequate, and to ensure that access ways to the underground facility are not located in areas subject to flooding inundation.

3. Mechanical and physical properties of the candidate horizon are needed to ensure that underground openings (shafts, ramps, drifts, and boreholes) can be designed and constructed to require only minor maintenance for the operational life of the repository. This determination must consider the nature of both the rock mass (fractures, voids, moisture content, etc.) and the intact rock properties as they are affected by elevated temperature. Thermal properties are needed to design the emplacement configuration for the waste packages so that temperature constraints will be within design limits. Additional needed site data includes the radiation shielding characteristics and radon emission rates for the host rock.

4. Site hydrologic data (related to the potential existence and quantitative description of perched water) are needed to choose appropriate sizes for pumps for water removal and to evaluate sources for the water needed to support repository operation.

5. Site meteorological data are required to design the underground ventilation system.

Preclosure tectonics data needs

Data are needed on the subsurface geometry of local faults (within about 25 km of the site), on the amount of total slip along such faults, and on the extent to which faulting events involve slip on more than one fault. This information can affect the evaluation of the design basis for ground motion, including time histories and the corresponding response spectra for facilities. In addition, the estimated combined potential for ground motion from all faults and the probability for fault displacement greater than 5 cm in the repository and at the location of facilities important to safety may be affected. The rate of total slip along various faults may affect the estimated probabilities of various size faulting events. The relative importance of contemporaneous slip on associated faults may affect estimates of magnitude, probability of faulting, and the characterization of single-event displacements.

Summary of preclosure data needs

Information is needed for radiological safety and waste retrievability performance evaluations, for design of surface and underground repository facilities, and for nonradiological safety and worker safety evaluation. Geologic information is needed to locate repository facilities, and to evaluate potential tectonic and volcanic hazards. Information on the spatial distribution of host rock characteristics and site geometry is needed to locate and design the underground facility. Data on surface characteristics are needed for seismic design. Meteorological information is needed for safety evaluations. Fault detection and characterization for the Yucca Mountain region is needed for seismic design and performance evaluation. Detailed information on potential faulting in the repository block during the preclosure period is needed primarily for retrievability evaluation.

### 8.4.2.1.3 Methods for obtaining needed site data

This section briefly reviews the methods available for obtaining needed data. The methods are broadly grouped into categories for obtaining surface and subsurface data, and the methods for subsurface characterization are emphasized. These methods have been further categorized according to whether testing is based at a surface or subsurface location. The scale of the data, or volume of rock influenced, is also discussed. Scale and representativeness of data from the various methods are discussed in greater detail in Section 8.4.2.1.4.

#### 8.4.2.1.3.1 Characterization methods for obtaining surface data

The postclosure and preclosure data needs were discussed previously in Sections 8.4.2.1.1 and 8.4.2.1.2. The surface data needs are summarized as

1. Magnitude of surface infiltration and the processes that control influx.

2. Surface expressions of local faulting and information concerning the nature of faulting and other structural features within the repository block.

3. Surface evidence related to the regional volcanic history and eruptive and intrusive processes.

4. Surface topography for locating surface facilities and shafts beyond potential flood zones.

5. Soil properties for designing surface facilities and evaluating erosion processes.

6. Meteorological data for radiological release analysis and ventilation system design for surface and subsurface facilities.

The surface data needs can generally be met by measurements at the ground surface, such as meteorological monitoring, radiometric monitoring, geodesy, seismic monitoring, evapotranspiration studies, geologic and surficial deposits mapping, and geophysical methods. Standard methods are proposed in Section 8.3.1 for these measurements. Several of the data needs will require shallow borings and the construction of berms, trenches, flumes, scour chains, and pits. Test methods will include the instrumentation to monitor changes in conditions within the test areas, as well as visual observations.

### 8.4.2.1.3.2 Characterization methods for obtaining subsurface data

The characterization methods for obtaining subsurface data are discussed by the location at which the methods are applied (surface and subsurface).

<u>Surface-based methods</u>

Two general methods are available for characterizing subsurface conditions remotely from the surface: geophysical methods and borehole methods. Geophysical methods include seismic, electromagnetic, and resistivity methods used for detecting geologic anomalies, estimating the thickness and extent of stratigraphic units, and correlating various parameters from other site characterization methods. Interpreting data from these methods can be difficult if strongly contrasting properties are absent or if other information for correlation is unavailable. Detection of anomalies usually requires significant contrast in density, magnetic susceptibility, or electrical conductivity. Geophysical methods are desirable because they generally are not invasive and provide information on relatively large volumes of rock. These methods are most useful when the data can be correlated with information from boreholes or underground investigations.

Borehole methods include the use of core or rock samples recovered from drilling and downhole testing methods. Samples provide data on hydrologic, geologic, mechanical, and thermal properties. Limitations on borehole observations include the small scale of samples and of certain measurements, and the inherent directional bias of the borehole. Such limitations can be

addressed (at least along the borehole axis) by sampling and testing the rock matrix and fracture intersections over the length of a borehole. Also, directional variability of the data can be analyzed from borehole inclinations. Boreholes can also be used for collecting water and gas samples for chemical analysis and interpretation.

Borehole test methods are available for characterizing some of the hydrologic and mechanical properties and conditions in the subsurface and for geologic studies using many of the geophysical methods just discussed. Hydrologic methods such as pumping tests and tracer tests provide medium-scale to large-scale data, but they typically require simplifying assumptions on site conditions or processes to interpret the test data. This is also true for mechanical tests, such as stress measurements, where relatively small volumes of rock are influenced by the test. In general borehole geophysical methods, such as cross-hole seismic methods, test a smaller volume of rock than the surface-based methods, but they offer improved resolution and capability to correlate the data with information obtained from the core and other borehole methods.

## Subsurface-based methods

Subsurface-based methods are considered to include all test methods applied in underground excavations, including shafts, tunnels, drifts, and adits. Samples are readily acquired from excavated rock or from exposed underground surfaces during excavation. Information on fractures and faults collected from underground excavations is likely to be more representative than what can be obtained from borehole methods. Compared with boreholes, the scale of the rock exposed for testing and observation is several orders of magnitude greater, and the directional bias is substantially reduced. Large-scale features such as faults and fracture zones can be accessed and studied in detail, at scales that are unattainable from boreholes.

Large-scale hydrologic, thermal, and mechanical tests can be performed in underground openings, but the in situ or ambient conditions of the rock mass may be locally altered by the excavation process and exposure of the rock to atmospheric conditions. Excavation effects can be minimized by using careful blasting or mechanical excavation techniques, but some localized disturbance of the ambient conditions is unavoidable.

The borehole methods can be used for remote access to the rock mass from the underground openings. The combination of approaches serves several purposes: (1) rock outside the zone around the opening disturbed during excavation can be accessed; (2) multiple boreholes can be drilled at depth to evaluate the variability of properties and conditions at several nearby locations in order to evaluate the magnitude of any bias; and (3) small-scale data can be used to interpret the large-scale tests and for correlation with the geophysical data.

## Indirect methods

Various indirect methods are available for characterizing subsurface conditions. Outcrops are convenient for many test methods mentioned earlier, as well as observational methods (e.g., fracture mapping). However, outcrop methods have a greater uncertainty associated with the results because of

biased exposure, differences in physical and state conditions (weathering, stress state, moisture conditions, etc.), and possible spatial variability of structural characteristics between the outcrop and the subsurface location of interest. Despite these limitations, outcrop data are potentially useful if they can be demonstrated to support data from subsurface and borehole methods, thereby increasing overall confidence in site characterization.

### 8.4.2.1.4 Relationship of planned testing to data needs

This section explains how the sample and data needs identified in Sections 8.4.2.1.1 and 8.4.2.1.2 are addressed by the planned testing, thereby establishing the need for the various types of characterization activities. Those subsurface methods that could potentially impact site performance or influence other tests are emphasized. The planned tests are described more completely in Section 8.4.2.2. The particular test plan described in this document was developed in part based on the professional judgment of Project scientists and engineers from a knowledge of site conditions and processes and data needs. The types, numbers, and locations of tests that were selected collectively represent only one of various alternative strategies and approaches that could be taken that may be equally suitable to obtain the data needed to characterize the site.

#### 8.4.2.1.4.1 Addressing principal postclosure information needs

As suggested by Table 8.4.2-1, data needs for postclosure performance evaluation are dominated by the need to reduce uncertainty in the alternative conceptual models of unsaturated-zone flow and transport. Such uncertainties may be broadly categorized as model, parameter, and calibration. All three need to be investigated for model validation. Model uncertainties exist because the characteristics of the physical system are simplified for tractability, and so a particular model is not unique for a given physical problem. An appropriate way to address model uncertainty is to develop different models in parallel, and conduct field tests to evaluate which model is appropriate. Uncertainties on the parameters that are used as model inputs generally are treated as mathematical distributions based on property measurements. Properties data and state measurements that are areally distributed are needed to provide parameter distributions and initial conditions throughout the site area.

Information on hydrologic conditions and processes in the unsaturated zone will be provided by a combination of exploratory shaft facility (ESF) testing and surface-based testing. To evaluate model uncertainties in situ hydrologic tests in the ESF are planned to investigate moisture distribution and flow processes. The effects of fractures and other discontinuities and the effects of ESF construction on the rock mass will be emphasized. Fracture and matrix flow processes will be investigated at different scales by the planned percolation test and bulk permeability test. The Ghost Dance fault and other structural features will be observed and tested from long, intercepting drifts at the repository horizon. Geomechanical and hydrologic effects of construction will be investigated by the multiple purpose borehole

activity, the radial boreholes test, and the excavation-effects test in exploratory shaft ES-1. The excavation investigations study and other activities at the repository level in the ESF will provide additional geomechanical information on the effects of excavation. The ESF tests are discussed further in Section 8.4.2.1.5.1 (relationship between surface-based testing and testing in the ESF).

Sampling and testing associated with the systematic drilling program and the site vertical boreholes study will provide information on the distribution of hydrologic parameters and state variables across the site area. These surface-based programs will provide similar types of samples and data on in situ hydrologic conditions. They comprise nearly all of the borehole penetrations of the unsaturated zone within the conceptual perimeter drift boundary (CPDB) or in the immediate vicinity. (The CPDB is the projection to the surface directly above the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6. Both the CPDB and perimeter drift are discussed more thoroughly in Section 8.4.2.2.) The access and samples provided by these activities will also address the need for information on geochemical characteristics and gaseous-phase conditions and processes. The strategy for locating the holes is developed in Section 8.4.2.1.5 and in the description for Activity 8.3.1.4.3.1.1.

Information on the waste package environment and geomechanical rock mass will be acquired from planned ESF construction and testing at the repository horizon. Rock-mass mechanical, hydrologic, and chemical responses will be investigated under experimental conditions of stress and temperature. The effects of ESF construction on the geomechanical and hydrologic characteristics of the surrounding rock mass will be investigated. Information on the spatial variability of properties and conditions (obtained from the surface-based drilling program) will be the basis for applying the results from ESF testing to the overall repository area.

Alternative conceptual models (ACMs) for site conditions and processes affecting postclosure performance generally are addressed by the activities described for other data needs. Evaluation of postclosure tectonic processes is an example of where alternative conceptual models have distinct data requirements. Scenarios for tectonic effects on waste isolation will be evaluated using information on the configuration of local faults, regional stress state, faulting history, and the history and style of recent volcanism, collected by a comprehensive program of site activities. These activities include geophysical exploration, remote sensing, trenching of faulted surface deposits, investigation of vein deposits, seismic and geodetic monitoring, and exploration of magnetic anomalies to determine the nature of volcanic origins. Other information needs for ACM evaluation will be addressed by (1) acquiring representative geochemical, unsaturated-zone hydrochemical, and saturated-zone hydrochemical data from surface-based boreholes for evaluating the temporal stability of the water table; (2) investigating scale-dependent rock-mass hydrologic and geomechanical characteristics in the ESF for evaluating modeling approaches, such as the effective continuum approximation; and (3) using surface-based boreholes and the subsurface access provided for borehole geophysical methods to investigate the geometry of fault blocks.

Information needs for natural-resource evaluation will be addressed by geophysical surveys, geochemical evaluations, and surface and subsurface sampling. Planned geophysical methods include high-resolution surface gravity and aeromagnetic surveys of the site area, seismic exploration for deep structure, and remote sensing for constitutive properties of surface materials. Geophysical requirements for mineral-resource evaluation will be integrated with related needs for the tectonics and rock-characteristics investigations. Planned subsurface sampling, in the absence of indications of significant mineral occurrences in the site area, will be based on drilling planned for other activities, including the systematic drilling program and the more remote geologic coreholes and volcanic holes.

Information on the spatial variability of properties and conditions will be obtained primarily by means of surface-based drilling. Vertical boreholes are a principal means for providing needed information on vertical and lateral variability at locations distributed across the site. Lateral variability is coupled to structural conditions that can readily be characterized from vertical boreholes, such as lithostratigraphy, lateral facies changes, or laterally heterogeneous conditions at the surface. Samples, logs, testing, and monitoring data from the systematic drilling program, the site vertical boreholes study, and other drilling will be used to infer the geologic history and structure of the site. Matrix properties data for thermal, mechanical, hydrologic, and physical properties models will be provided by spatially distributed boreholes. Models of variability for these properties will be considered in the evaluation of results from the systematic drilling program (Activity 8.3.1.4.3.1.1).

Sampling in the shafts and drifts of the ESF, in boreholes drilled from the ESF, and from surface outcrops is also planned to provide information on small-scale lateral variability. Boreholes will provide subsurface access for geophysical exploration by such means as borehole gravity and vertical seismic profiling. Geochemical and hydrochemical information and samples for analysis of natural tracers will also be obtained from surface-based boreholes. In addition, various surface-related activities, such as mapping, remote sensing, and geophysical surveys, will be used to characterize surface conditions and processes, interpolate subsurface conditions between boreholes, provide information for depths beyond the range of planned drilling, and explore for anomalies indicative of unexplored subsurface structures or mineral occurrences.

### 8.4.2.1.4.2 Addressing principal preclosure information needs

Geologic information needed for surface facilities design will be provided by drilling and trenching activities, for evaluation of the recurrence of seismicity and volcanism in the Yucca Mountain region. Ongoing meteorological monitoring will support the evaluation of wind loads, flooding potential, and radiological safety for the surface facilities. Drilling and testing activities at proposed locations for the repository surface facilities will provide information on surficial materials, foundation-bearing characteristics, seismic response, and erosion history.

Information on host-rock geometry over the site area will be provided for underground design by planned surface-based boreholes. Samples from these boreholes will also be used for the thermal/mechanical/hydrologic and physical properties models, which will be used to infer ground support and maintenance requirements, temperature constraints for the host rock, and radiation shielding properties over the site area. The long exploratory drifts from the main test level of the ESF will intercept major structures, such as the Ghost Dance fault, from which needed hydrologic and geomechanical information will be obtained. Responses of lithophysal tuff to repository-sized excavation and geomechanical testing will be investigated in the upper demonstration breakout room. These responses will be used to evaluate the sensitivity of lithologic constraints on the geometry of the repository.

Special trenching procedures will be used to investigate strike-slip displacement along major faults in the vicinity of the site. Extensive trenching will be done across Midway Valley, near the proposed location of the repository surface facilities.

### 8.4.2.1.4.3 Summary of how information needs are addressed

Information needs for both postclosure and preclosure design and performance evaluations will generally be met through a combination of surface-based and ESF activities. Samples, data, and other information from the surface-based drilling program will be used to address a variety of information needs. The areal coverage strategy of the systematic drilling program is simple and, on the basis of current understanding of site conditions and alternative conceptual models, appropriate for the various applications. A method for allocating samples to multiple uses is presented in Activity 8.3.1.4.3.1.1 (systematic drilling program). The relationship of testing in the ESF to surface-based testing is discussed further in Section 8.4.2.1.5.1. The activities described to this point do not involve excavation in the Calico Hills unit beneath the conceptual perimeter drift boundary or immediate vicinity. Section 8.4.2.1.6.1 further describes two characterization plans for the Calico Hills unit.

### 8.4.2.1.5 Representativeness of planned testing

The planned characterization program is expected to yield data that are representative of site conditions and processes, and to support the use of multiple approaches for demonstrating representativeness. A systematic approach to program planning, involving performance allocation as introduced in Section 8.1, was used to identify characterization activities that effectively respond to information needs specified in the issues hierarchy. The major field activities planned for site characterization are associated with the principal information needs discussed in the preceding section. The rationales for the locations and for the methods for conducting many of these activities are presented in Section 8.4.2.2.

The investigations detailed in Section 8.3.1 will be extensive, with intensive surface and subsurface coverage of the immediate site area. Results from surface-based and excavation-based activities such as geologic mapping, geophysical surveys, exploratory drilling, underground construction, and in situ testing will be used in multiple approaches to developing an understanding of variability in site conditions and processes. In one approach, predictive, quantitative descriptions of variability will be based on statistical analyses, and used to infer locations from which additional data would be collected to improve representation of site conditions. In another approach, descriptions of geologic, hydrologic, or geochemical characteristics will be based on observations and scientific inference, and will include the history of the natural processes that produced present conditions.

The planned characterization program is based on general technical criteria, statistical concepts, and site-specific information to the extent practicable. There is abundant information from Yucca Mountain and similar locations concerning geologic, hydrologic, geochemical, or other conditions and processes that affect site performance. This general and site-specific information constrains the conceptual understanding of site conditions and processes used in planning the characterization program. It also supports the expectation that representative data will be collected. A general discussion of the sources of variability in volcanic deposits is presented in this section to show that variability in tuff units at Yucca Mountain has nonrandom characteristics that can be appropriately investigated by spatially distributed, surface-based boreholes.

Requirements for achieving representative data from planned testing vary with the individual tests. The strategies for siting and design of different tests, especially surface-based tests relative to testing in the ESF, reflect different requirements for representativeness. A site-screening process used for siting the ESF is discussed in this section, in terms of how the location selected supports data representativeness. Tests planned for the ESF are discussed in general terms in this section, for the purpose of relating ESF testing results to the spatially distributed data from surface-based testing. This section also discusses how the surface-based program can be functionally separated into systematic and feature-sampling approaches, as a means for detecting bias in data collected, and as a mechanism for responding to new site information as it becomes available.

This section discusses the representativeness of planned testing using several approaches, which are summarized as follows:

1. Both surface-based testing and testing in the ESF will be used to detect and characterize the variability in site conditions and processes and to address information needs identified in the performance assessment process and described in the preceding portion of 8.4.2.1.

2. ESF investigations will be used to provide representative results for the site because the current understanding of overall site conditions and processes supports this approach.

3. Systematic sampling and feature sampling will be used to evaluate sampling bias, and geostatistical methods will be used to quantify spatial variability and to estimate confidence in the understanding of spatial variability.

4. The geostatistical approach will be used to characterize the variability in key rock properties because information available about characteristics of tuff units at Yucca Mountain and a general understanding of volcanic deposits support this approach.

The following subsections explain these approaches in more detail, and conclude that they represent reasonable approaches to ensuring data representativeness. This outcome is also supported through the planned iterative reevaluation of information from the site, for example, as discussed for the geologic model in Investigation 8.3.1.4.2 and the statistical modeling of Study 8.3.1.4.3.2.

### 8.4.2.1.5.1 Relation between surface-based testing and testing in the exploratory shaft facility

The planned testing program in the ESF consists of several (more or less exclusive) categories of tests: (1) tests intended to investigate the processes and phenomena contributing to waste-isolation performance of the host rock, (2) tests to directly investigate the effects of ESF construction, and (3) tests to investigate undisturbed in situ conditions at the ESF location. Many of the tests fall into the first and second categories, for which the primary objective is to first investigate site processes important to waste isolation and then correlate these processes with the conditions present (natural or artificially controlled), through the use of models. Whether the test conditions and the observed responses are representative of the site area will be evaluated using data on site conditions from surface-based boreholes, and from observations of the range of conditions and processes evident from the ESF. Spatial variability of site conditions will be evaluated statistically, using both classical and geostatistical approaches. The resulting statistical descriptions of parameter variability, and the models relating conditions and processes, will form the basis for extending the results from these ESF tests to the overall site area. The remaining category of tests (to characterize undisturbed conditions) may be regarded as similar to surface-based borehole tests, although enhanced by the subsurface access and information from other testing, facilitated by the ESF. For most such tests, the extension of results from the ESF to the site area will be possible through the use of parameters or conditions that can be characterized from surface-based boreholes.

The set of parameters that will be used to extend information from testing in the ESF to the overall site area depends on the individual tests and can be fully specified when additional site-specific information is available. A basic set of parameters will be collected intensively from each planned borehole within the conceptual perimeter drift boundary or immediate vicinity, as described for the systematic drilling program (Activity 8.3.1.4.3.1.1). Other such parameters will be characterized by additional measurements either in open boreholes or on core samples. Alternatively, an

approach will be used whereby parameters that are difficult to measure are correlated with the basic, index parameters in a scheme such as the conceptual strategy outlined in Section 8.3.1.4.3.1.1. Chapter 2 describes how geomechanical properties such as intact rock compressive strength are correlated with matrix porosity, adjusted for clay content. Similar relationships are expected to be developed for other parameters, as additional information becomes available during site characterization.

Many of the parameters that affect ESF test results can be measured or sampled in boreholes, with a few exceptions. In particular, borehole characterization of fractures or other discontinuities is limited by detection bias and scale effects. To the extent that generalizations about smooth variability of rock characteristics (discussed in Section 8.4.2.1.5.4) hold for tuff units at Yucca Mountain, the strongest local rock-mass variability is probably associated with the distribution and characteristics of fractures, especially tectonic fractures. The limitations of borehole methods principally affect characterization of hydrologic and large-scale geomechanical conditions. Accordingly, the in situ hydrologic and geomechanical tests planned for the ESF will incorporate an assessment of sensitivity to fracture parameters and a comparative evaluation of test conditions relative to fracture conditions encountered throughout the ESF. Extensive drifting in the test facility and the drifts planned to intercept known or inferred structures at the repository horizon will provide ample opportunities to observe the range of fracture characteristics.

In summary, the representativeness of data from many ESF tests is based on the capability to identify and investigate the variability of processes that control site performance, and the relationship of these processes to variability of site conditions. Many of the relevant site conditions can be effectively explored by surface-based drilling and testing. For fracture-related characteristics, the extent of exploratory excavation at the main test level of the ESF is expected to provide abundant data for evaluating the range of variability for such characteristics across the overall site area.

### 8.4.2.1.5.2 Representativeness of the exploratory shaft facility (ESF) location

As described in the previous section, tests planned for the ESF generally are intended to investigate (1) processes and phenomena that contribute to performance of the host rock (see discussion of model uncertainties in Section 8.4.2.1.4.1); (2) rock-mass response to ESF construction; or (3) undisturbed in situ conditions at the ESF location. In accordance with the discussion in the previous section, the principal representativeness constraints on the ESF location are (1) whether the rock characteristics are such that the processes extant throughout the site can be adequately investigated and whether ESF test results can be readily extended to the overall site area, and (2) that the local rock characteristics are such that difficult shaft construction conditions, which would be nonrepresentative of conditions encountered in repository excavations, are avoided. This section presents the results of the original ESF location screening and more recent syntheses of site data, and discusses the assessment of new information

during site characterization to show how these constraints are addressed by the planned ESF location.

The ESF location screening analysis (Bertram, 1984) considered five alternative sites distributed in the central part of the conceptual perimeter drift boundary and to the north. The sites differed markedly with respect to terrain, geologic aspects, and proximity to features of geologic or hydrologic interest. A broad range of screening criteria was used, including shaft-construction feasibility, cost, environmental concerns, expected data representativeness, and general repository design considerations. About 46 percent of the weighting in the screening process was given to criteria related to data representativeness, including extent of site area explored, proximity to potentially adverse structures, thickness of target units, and repository design compatibility. The Coyote Wash location was selected for several reasons, including (1) subsurface exploration within about 1,000 to 2,000 ft of the location would result in sampling of a significant portion of the area within the conceptual perimeter drift boundary; (2) conditions appear favorable for shaft construction; and (3) geologic structures potentially adverse to repository performance such as the Ghost Dance fault, Drill Hole Wash, and the imbricate fault zone east of the conceptual perimeter drift boundary are readily accessible.

Geologic conditions in the vicinity of the planned ESF location have already been sampled by several boreholes, including USW G-4, which is located about 715 ft from the planned centerline of shaft ES-1. Data from this borehole are considered representative of the planned ESF location in the analysis of Nimick et al. (1988) discussed later. Geologic conditions and saturated-zone hydrologic conditions for this borehole are reported in Spengler and Chornack (1984) and Bentley (1984), respectively. USW G-4 was sited with the intention of evaluating conditions at the proposed ESF location, and the results were consistent with expected lithostratigraphic and structural conditions, which comprised part of the basis for the selection decision (Bertram, 1984).

The functional stratigraphy proposed by Ortiz et al. (1985) distinguishes different units on the basis of (1) degree of welding inferred from matrix porosity, (2) geologic classification based on lithostratigraphy and eruptive origin, and (3) degree of zeolitization. Quantitative mineralogical information from 14 drillholes in the vicinity of Yucca Mountain was evaluated by Campbell (1987), with the objectives of (1) evaluating the unit divisions of Ortiz et al. (1985) with respect to data not used in its formulation and (2) evaluating lateral variation in the distribution of zeolites and other sorptive minerals. Data from a large proportion of core and cutting samples were found consistent with the stratigraphic model. This is essentially the same model used for defining the host rock unit in the repository conceptual design and for performance allocation. As expected, information from boreholes located at some distance from the site area, such as wells J-12 and J-13 near Fortymile Wash to the east, varied somewhat from conditions at the site. This variability suggests that the methodology used was sufficiently sensitive to support the finding of relatively homologous mineralogical conditions, and conformance with the functional stratigraphy, within the site area.

Another analysis by Nimick et al. (1988) uses various published descriptions of rock characteristics based on existing boreholes distributed throughout the site area and other information about the Yucca Mountain site to evaluate the representativeness of the ESF location. Statistical comparisons are used for mineralogic, hydrologic, and thermal/mechanical properties data from USW G-4 and other boreholes throughout the site area. This analysis confirms that the planned ESF location is representative of the site area for the following characteristics: unit thickness, lithophysal abundance and certain other lithologic characteristics, overburden thickness and vertical in situ stress, grain density, matrix porosity, geomechanical intact rock properties, ground-support requirements, and certain design requirements. For fault zone and fracture characteristics, the available borehole information is inherently unsuited to statistical evaluation for the reasons discussed in Section 8.4.2.1.3. For these characteristics, however, there are special measures planned within the ESF, particularly the long exploratory drifts at the repository horizon, which will provide representative information on the range of site conditions (Section 8.4.2.1.5.1). These long drifts will total approximately 5,600 ft in length and will extend in three widely spaced directions from the dedicated testing area. The location and general characteristics of the structures to be intercepted by these drifts have been inferred from extensive surface mapping, trenching studies, and geophysical surveys, which are summarized in Chapter 1.

In summary, rock characteristics that can be investigated from boreholes, and for which data are available, indicate that the planned ESF will provide underground test locations that support test results that will be representative of site conditions and processes. For other parameters affecting test results, such as fracture and fault zone characteristics, the planned ESF includes extensive excavation to intercept and characterize features representing the range of conditions and processes in the host rock.

### 8.4.2.1.5.3 Statistical representativeness

This section describes differences between the systematic drilling program and the balance of surface-based drilling, explains how the planned characterization program provides for detection of bias in collected data, and discusses the importance of the geostatistical approach and how it will be evaluated using information from an integrated drilling program.

Differences between feature sampling and systematic sampling

The systematic drilling program (Activity 8.3.1.4.3.1.1) is different from previous drilling, and the other drilling planned for site characterization. This systematic program is associated with a deductive, probabilistic approach, and the balance of drilling with a more deterministic, feature-sampling approach to site characterization.

In the feature-sampling approach, the location of a single borehole or set of several boreholes is chosen for testing a specific hypothesis at that location. For example, an exploratory borehole could be located where there are anomalous surface geophysical indications to test the related hypothesis of a buried structure, possibly of a particular type. If the structure is

not observed as a result of the drilling, another hypothesis for the sources of the anomaly would be proposed and tested to reduce uncertainty in the conceptual geologic model. If the predicted structure was observed as a result of drilling, confidence in the predictive nature of the conceptual model is improved.

The principal objectives of the systematic program are to characterize spatial variability, and to provide areal coverage of the site for investigation of geologic, hydrologic, and geochemical parameters. The use of existing boreholes and planned boreholes of the feature-sampling program, in conjunction with the systematic program, will significantly increase the data available for evaluation of spatial variability. This, in turn, will reduce the cost of site characterization, and the extent of surface and subsurface disturbance.

The feature-sampling approach supports the systematic drilling program in another way. Systematic sampling as proposed (Activity 8.3.1.4.3.1.1) does not necessarily sample extreme values of structural or state variables that may be expected from foreknowledge of the site, and the feature-sampling approach is needed to ensure that statistical descriptions of variability appropriately treat the possible range of site conditions in the alternative conceptual models.

Representative sampling approach

The feature-sampling and systematic-sampling approaches differ with respect to the information used to site boreholes. Many of the proposed boreholes of the feature-sampling program are planned to investigate structures of interest, such as the Solitario Canyon fault, Ghost Dance fault, or conditions underlying the crest of Yucca Mountain. Because the conceptual perimeter drift boundary (CPDB) is essentially bounded by fault structures and because site performance may be affected by faults, the feature-sampling program may be intrinsically biased particularly for evaluation of state variables. Accordingly, seven of the twelve planned holes of the systematic drilling program are sited to provide approximately uniform areal coverage of the CPDB, in conjunction with planned boreholes of the feature-sampling program (including USW holes UZ-2, UZ-3, UZ-7, and UZ-8; Section 8.4.2.2.1). These seven boreholes are similar in number to the planned feature-sampling program within or near the CPDB, which is appropriate if statistical comparisons are to be used to evaluate bias. Samples from these holes, in conjunction with the planned feature-sampling program, will address needs of all planned test programs, including thermal and mechanical properties (Investigation 8.3.1.15.1) and mineralogy/petrology/geochemistry studies (Investigation 8.3.1.3.2), which do not call directly for boreholes as described in Section 8.3.1, but require "representative" samples from distributed locations to detect variability and to evaluate trends.

Geostatistical approach

Geostatistics, proposed for Study 8.3.1.4.3.1, is directly related to the probabilistic analyses needed to address such performance objectives as the ground-water travel-time requirement of 10 CFR 60.113 and the radionuclide release limits of 40 CFR Part 191, Subpart B. Regulatory objectives

generally are stated in terms of limiting values, with an overriding requirement to provide reasonable assurance, with allowance for the time periods and uncertainties involved. For certain objectives, an allowable probability for exceeding the limiting value (or some function thereof) is also specified (e.g., 40 CFR 191.13). In either instance, demonstration of compliance will be probabilistic, whether to provide quantitative support to the assertion of reasonable assurance or to directly address prescribed probability levels. Geostatistical methodology provides estimates of confidence in understanding of spatial variability, in probabilistic form.

Geostatistics (or spatial statistics) is the part of applied statistics that helps provide an analysis and a mathematical description of spatially related geologic data. Sample values in geologic deposits usually are not independently random variables but are spatially related. Classical statistical methods typically assume that observations are independent, which may be inappropriate for geologic deposits. Geostatistical methods quantify spatial variability as a function of distance between sample locations and are therefore well suited for modeling and interpolating the three-dimensional variability of the measured properties in a geologic deposit (Buckley et al., 1986).

The basic data for geostatistical evaluation are observations of key properties, separated by distances that range from a few inches to the largest dimension of the CPDB. Outcrop studies and studies in the ESF will provide the data for small separation distances (less than 500 ft). Existing boreholes, planned boreholes of the feature-sampling program, and the seven boreholes of the systematic drilling program that are distributed for areal coverage will provide the data for large spacings (greater than 3,000 ft). The other five boreholes of the systematic drilling program are intended to provide sufficient data at intermediate spacings of about 1,000 feet. The five boreholes are clustered near several planned boreholes of the site vertical boreholes study (i.e., USW holes UZ-7 and UZ-8 and UE-25 holes UZ#9, UZ#9a, and UZ#9b), in order to maximize the number of borehole pairs at small spacings. The five-borehole array described in Section 8.3.1.4.3.1.1 is flexible and could be modified without detriment to geostatistical objectives. But as planned, this array lies outside the CPDB and thus avoids direct effects on the repository in accordance with 10 CFR Part 60.15(d).

## 8.4.2.1.5.4 Volcanic stratigraphy

The variability of the rock characteristics of tuff units at Yucca Mountain was produced by variability of the volcanic sources, eruptive processes such as sorting and turbulence, local conditions at the Yucca Mountain location during the eruptions, posteruptive alteration, and tectonic deformation since the Miocene time. Although complex, these are known geologic processes that produced systematic variations in the ash deposits. Moreover, the volume and extent of ash flows such as that which formed the Topopah Spring host rock were so enormous that heterogeneities at the scale of the Yucca Mountain site are likely to be minor relative to overall, large-scale variability. Tectonic deformation may have had more local effects, as described later. The discussion in this section supports the proposition

that variability of key rock properties has a significant, nonrandom, systematic component that can be effectively characterized using the planned geostatistical approach.

Each geologic unit in the tuff sequence may be characterized as consisting of one or more of the following: (1) multiple ash flows consolidated into a cooling unit with characteristic mineralogic and petrologic differentiation; (2) clastic material; (3) ash fall deposits; or (4) a zone of secondary alteration (e.g., zeolitization), which may transect lithostratigraphic units. Whereas vertical variability can be associated with the sequence, thicknesses, and variation within these layers, lateral variability is associated with their continuity.

Lithostratigraphic continuity within the site area is important for statistical modeling of spatial variability. Geostatistical methods will be used to analyze unit thickness and depth-averaged properties for thicker units at Yucca Mountain, without much emphasis on lithostratigraphic continuity. However, for thinner units (e.g., PTn or TSw3 functional units of Ortiz et al. [1985]), there is evidence of lateral termination (especially of subunits) over distances smaller than the separation between existing boreholes (Scott and Castellanos, 1984). The lateral continuity of a property of interest in a volcanic tuff unit is strongly related to processes occurring during the eruption and emplacement of the unit.

Trends in the physical properties and composition of pyroclastic-flow and pyroclastic-fall units are inherited from magmatic sources, imposed by emplacement mechanisms, or imposed by postdepositional modification and alteration. The eruption of a Miocene tuff unit in the vicinity of Yucca Mountain, like many tuff sequences, is likely to have been from a magma chamber that was chemically stratified with more silicic products evolved early in the eruption, and more mafic products erupted later (Smith, 1979). Such chemical stratification is typically associated with an increase in the proportion of crystalline to glassy pyroclasts in the more mafic deposits.

Eruption can impart another type of variability based on emplacement processes. Ash-fall units are subject to sorting by size; heavier pyroclasts fall closer to the vent than lighter ones, resulting in progressive decrease of median grain size with distance from the eruptive source. Vertical variations within ash-fall units can be expected if the intensity of eruption changes with time (Fisher and Schminke, 1984). Also, the total volume of an erupted ash-fall unit tends to control the areal distribution. In general, the larger the volume, the more area blanketed by the tephra and the thicker the deposit at a given distance from the source (Fisher and Schminke, 1984).

For pyroclastic flow deposits, changes in grain size, fabric, sorting and composition are more complex relative to the hydrodynamically simpler ash-fall units. In general, pyroclastic flow units can be expected to vary with distance from the source vent as a result of pre-eruptive topography, and according to the energy of the eruption. An idealized sequence of deposits and textures within a pyroclastic flow event has been proposed by Sparks et al. (1973), and most such flows conform in some way to the idealized scheme (for example, see Fisher and Schminke, 1984). The deviation of actual sequences from the idealized scheme may appear random, but in many

instances can be associated with variation in the energy of eruption or the topography onto which the flow was erupted.

Postemplacement modification processes are of several general types: welding/compaction of the deposit, chemical changes such as zeolitization and vapor-phase alteration, and fracturing due to thermoelastic cooling stress or subsequent tectonic effects. The degree of welding and compaction of an ash-flow unit is primarily a function of the volume and thickness, temperature of emplacement, and to a lesser extent composition. The main factor in welding is the time the deposit remains above a minimum temperature, thus in general, the thicker a deposit, the more likely it is to weld. Likewise, hotter deposits are more likely to undergo welding. The factors involved with welding have been explored by many investigators (for example, Sheridan and Ragan, 1976; Peterson, 1979). In addition to gradual lateral trends in welding, abrupt changes can be caused by topographic effects or the amount of water vapor present locally in the pyroclastic flow (caused, for example, by water present on the pre-eruptive surface).

Vapor-phase alteration tends to be confined to the upper part (about half) of the thickness of welded ash-flow deposits. The distribution of alteration is, in general, related to the composition and quantity of volatile phases in the deposit after it comes to rest. Zeolitization is partly related to vapor-phase alteration. Further production of zeolites can be caused by hydrologic processes that may be essentially unrelated to deposition and immediate postemplacement alteration.

Cooling fractures tend to form perpendicular to the free surface of a flow, in response to stress caused by differential contraction. Cooling fractures, therefore, tend to be vertical, and spatial variation in the frequency or distribution is related to variations in characteristics that control welding, fabric, and cooling (i.e., thickness, temperature, composition, topography, etc.). The scale of variability in the distribution of cooling fractures may be larger than that for tectonic fractures, based on the frequency of faults at Yucca Mountain and the association of fracture frequency with proximity to fault structures.

The scale of each of these effects is variable; Table 8.4.2-3 relates the different effects to gross differences in scale of variability. It is likely, based on studies of various tuff sequences, that the variability observed in characterization of the Yucca Mountain site will conform to these types of variability, and associated trends in scale. However, no ash-flow sequence has been explored by means of systematically located boreholes in the manner planned for Yucca Mountain, therefore the observed variability may appear to be random at early stages of exploration.

Table 8.4.2-3. Scale of variation of geologic-unit properties

| Property | Principal scale of variation |
|---|---|
| Chemical composition | Whole deposit, both vertically and laterally |
| Grain size | Centimeter to meter |
| Sorting | Whole deposit, both laterally and vertically |
| Fabric | Vertically, meter scale; laterally, whole deposit |
| Welding | In general, tens of meters vertically, and whole-deposit laterally; abrupt changes in deposition conditions (pre-eruptive surface water or topography) can bring about tens of meters-scale lateral changes |

In summary, characteristics of volcanic units exhibit systematic variation at different scales, because of the nature of the formative processes. It is expected that during site characterization, parameters affecting site performance (e.g., hydraulic conductivity, compressive strength, alteration) will be found to also vary systematically because they depend on the basic unit characteristics and formative processes. The planned integrated surface-based exploration program is appropriate for detecting and characterizing systematic variability and will support the performance allocation goals for repository design and performance.

### 8.4.2.1.5.5 Drifting to the southern part of the repository block

The southeastern margin of the proposed repository block has a higher density of faulting than other areas within the CPDB, as mapped or inferred from surface geologic indications (Scott and Bonk, 1984). The SCP contains plans to drill several surface-based vertical boreholes in this general area, including drilling of boreholes SD-7 through SD-12 of the systematic drilling program (Activity 8.3.1.4.3.1.1), and deepening of unsaturated-zone boreholes USW UZ-7 and USW UZ-8 (Activity 8.3.1.2.2.3.2). The extent to which borehole information is sufficient to establish the range of geomechanical and hydrologic site conditions in this region has been the subject of documented comments to the DOE (e.g., Linehan, 1987). As a result, questions have been raised regarding the need to drift from the ESF location to the southern part of the block.

Although drifting to the southern part of the repository block could provide useful information for assessing data representativeness, a decision was made not to undertake this effort. The planned long drifts from the ESF, including drifting to the imbricate fault structure to the east, are expected to provide information on the hydrologic and geomechanical significance of features that are similar to those that would be encountered in the southeastern part of the site. Once information from planned drifting and surface-based drilling is available, the necessity for additional drifting will be reevaluated. If a need for additional drifting is determined, analysis has shown (F&S, 1988) that construction from the main test level of the planned ESF to the southern portion of the repository block is feasible with respect to engineering concerns and personnel safety and is not precluded by planned construction and testing. The planned boreholes will define the stratigraphic controls on the elevation of the repository horizon with which such an exploratory drift would be integrated.

### 8.4.2.1.6 Conditionally planned subsurface characterization activities

Several site characterization activities exist for which conceptual plans are provided in Section 8.3.1, but which are indefinite either because the technical details including location are not yet available or because a decision to proceed depends on the outcome of other activities or technical evaluations. These conditional activities are discussed here for completeness.

Two major decisions concerning the approaches to be used for obtaining information in the subsurface have been deferred, namely, whether to excavate in the Calico Hills nonwelded unit and whether to drift to the southern part of the repository block. Discussed below are options for obtaining the needed information for the Calico Hills unit and for the southern part of the repository, and factors that will be considered in determining which approaches will be used. In addition, various other conditionally planned activities of lesser scope are described.

#### 8.4.2.1.6.1 Characterization of the Calico Hills nonwelded unit

As a result of the performance-allocation process, the Calico Hills nonwelded unit has been designated the primary barrier to ground-water flow and radionuclide transport. As such, the flow processes and conditions in that unit must be sufficiently understood to have a high degree of confidence in the effectiveness and limitations of that barrier. Various methods of gathering data from the Calico Hills unit are possible. These methods include indirect techniques (such as remote sensing or evaluation of the same or other rock units in another location) and direct techniques (such as drilling, mapping, or drifting). Whatever methods are chosen, assurance must be given that the gathering of data would not jeopardize the effectiveness of the unit as a barrier. Because the analyses are not sufficiently mature to effectively compare the risks and the benefits of gathering in situ data, the decisions have been deferred as to whether to proceed with the excavation, what means would be used to excavate, and where the excavation would be

located. The DOE is currently evaluating (1) the need to extend the exploratory shaft into the Calico Hills unit to gather data and (2) the impacts an excavation into the unit would have on the performance of the site. The decision will be based on a review of the data needs for this unit, an analysis of the risks and benefits of acquiring these data with a variety of techniques, and an evaluation of the potential impacts on site performance. Before taking action, the NRC will be consulted on the basis for the decision. Some of the factors being considered in determining if the exploratory shaft should be extended into the Calico Hills unit are briefly discussed below.

The Calico Hills nonwelded unit is composed of both vitric and devitrified facies. The devitrified facies is pervasively zeolitic and is, therefore, generally referred to as the zeolitic facies. The zeolites are potentially important to long-term isolation because of their capability to significantly retard transport of radionuclides (Daniels et al., 1982; DOE, 1986b). Thickness of the zeolitic facies generally increases from the southwest to northeast beneath Yucca Mountain. Beneath the northern and northeastern parts of the central block (including the proposed locations for the exploratory shafts), the Calico Hills nonwelded unit is almost entirely zeolitic (Nimick et al., 1988). The saturated matrix permeability of the zeolitic tuff is comparable to that of the overlying Topopah Spring welded unit, and generally is several orders of magnitude less than that of the vitric facies of the Calico Hills unit (Peters et al., 1986; Montazer and Wilson, 1984). The porosity of the nonwelded Calico Hills tuff matrix is about 30 percent. The thickness of the unsaturated portion of the unit ranges from about 100 m to about 250 m across the central block (Montazer and Wilson, 1984). At the proposed location of ES-1, the unsaturated thickness of the unit is 127 m (416 ft).

Data needed for characterization of the Calico Hills unit are closely aligned with data needs for postclosure performance evaluation described in Section 8.4.2.1.1. Data needed that are specific to understanding the contribution of the Calico Hills unit to postclosure performance are

1. Knowledge of hydrologic properties of matrix, fractures, and faults (including statistical distributions) over a range of scales to evaluate alternative conceptual models of conditions and processes in the Calico Hills unit; and information on whether flow is occurring in fractures or faults, on matrix and fracture saturation conditions, and on other characteristics indicating the nature of flow, including conditions under which fracture flow might occur.

2. Information on the heterogeneity of the unit with respect to flow and transport properties, and on the hydrochemistry and isotopic age of in situ water, to evaluate the occurrence of and potential for moisture flow in fractures in the Calico Hills unit, and to compare with conditions and processes in the overlying welded units.

3. Data on bulk rock permeability in the Calico Hills unit, at a range of scales and under controlled conditions and information on the nature of flow phenomena at the contact between the Topopah Spring welded unit and the Calico Hills nonwelded unit that will support

evaluations of the influence of geohydrologic structures on two-dimensional flow.

This information is needed to assess the flow paths and flux of moisture through the Calico Hills unit under conditions associated with expected and disruptive scenarios that will be evaluated as part of total system performance. The available methods for obtaining this information and their advantages and limitations are now briefly discussed below.

Characteristics of the Calico Hills nonwelded unit could be estimated from information obtained from other unsaturated tuff units. This approach would present little significant risk to site performance. In a second option, hydrologic properties, system geometry, extant processes, and initial boundary conditions for modeling could be estimated using data from the nonwelded and welded units above the Calico Hills unit. The usefulness of this approach is difficult to estimate because it is not currently known to what extent and how information from the other units could be correlated to the characterization of the Calico Hills unit. Although some constraints probably could be placed on flux and flow paths under present conditions, not directly observing the Calico Hills unit may result in an unacceptable degree of uncertainty about the characteristics of this unit and how they would affect flow under conditions associated with the full range of scenarios needed to assess total system performance.

Another option is to acquire data from outcrops of the Calico Hills unit. Although this approach would allow direct observation of the same hydrogeologic unit as that occurring in the subsurface beneath the site, certain limitations would apply. The nearest substantial outcrop is approximately one mile north of the CPDB in Yucca Wash. The degree of zeolitization of this outcrop is different from the zeolitization in the Calico Hills unit that has been penetrated by existing boreholes within or in the immediate vicinity of the CPDB. This difference in zeolitization would affect hydrologic and transport properties of the unit. The physical properties and in situ hydrologic state of the outcrop, including fracture characteristics, matrix saturation, and in situ matrix moisture potential, probably would not be representative of the unit beneath the site. This is because the outcrop is weathered, has smaller overburden pressure, and is closer to the volcanic source area than the subsurface component of the unit.

Planned boreholes of the feature-sampling program and the systematic drilling program (Section 8.4.2.1.5.3) will penetrate the Calico Hills unit and provide information and samples from it. Boreholes could also be drilled from the main test level of the ESF to the Calico Hills unit. Testing of the samples obtained from boreholes will provide information on heterogeneity of matrix parameters on a site scale. Boreholes within the CPDB are preferred because (1) planned boreholes will provide heretofore unavailable information on matrix properties and in situ saturation within the repository block, and (2) a current understanding of site conditions and processes would allow an evaluation of the representativeness of information from outside the CPDB. Samples from boreholes have some limitations, because they provide little information about the distributions and flow characteristics of fractures and faults.

Currently, five boreholes penetrate the Calico Hills unit within the CPDB (USW H-4, USW H-5, USW WT-2, USW UZ-6, and USW G-4). The drilling methods used for these penetrations did not permit acquisition of saturation profiles because of sampling limitations or the use of drilling fluid. For this and other similar reasons, a comprehensive set of hydrologic information was not obtained from any of the existing boreholes. Further discussion of the nature and amount of fluid lost during drilling at the site is provided in Section 8.4.2.2. These boreholes did provide mineralogic, petrologic, lithostratigraphic, and some hydrologic data that will be used as corroborative information to develop the geologic, hydrologic, and geochemical models of the site during site characterization. Existing and planned borehole penetrations through the repository horizon into the Calico Hills unit will be accommodated in pillars in the Topopah Spring unit within the conceptual repository design. Risks associated with penetrating the Calico Hills unit by boreholes are considered minimal because of the expected ability to seal boreholes, as supported by analysis (Section 8.3.3.2) and by testing and modeling reported in the literature (also reported in Section 8.3.3.2). Impacts of the existing and planned borehole penetrations of the repository horizon and the Calico Hills unit on postclosure site performance are evaluated in Section 8.4.3.

Penetration of the Calico Hills unit by underground excavation would allow for scale effects to be readily investigated. Macroscopic behavior of the rock mass could be monitored for validation of concepts of flow in unsaturated, fractured nonwelded tuff. Specific questions regarding flow paths (by lateral movement at unit contacts and through a fault) could be investigated, and bulk rock-property values could be measured.

The current ESF design does not show the extension of the exploratory shaft ES-1 or any drifting in the Calico Hills; however, sufficient flexibility exists in the design to incorporate these activities if a decision is made to extend the shaft and to develop drifts. Analysis has shown (F&S, 1988) that extending ES-1 and drifting in the Calico Hills would be feasible with respect to engineering concerns and personnel safety, so this option is not precluded by planned construction and testing. If the decision is made to conduct in situ tests in the Calico Hills nonwelded unit, the planned activities will be described in semiannual progress reports and in a study plan.

### 8.4.2.1.6.2 Other conditionally planned activities

A practical drilling method for dry, continuous coring to depths of up to 2,600 ft in fractured tuff is needed for site characterization, but has not yet been demonstrated. The ODEX method used previously at Yucca Mountain did not penetrate, and the reverse vacuum method did not provide sufficient samples for analysis of in situ matrix saturation and flow properties. An alternative method will be evaluated by means of one or more prototype holes to be drilled outside the CPDB near the UE-25 UZ#9 complex of holes, early in the characterization program. A general preferred method based on existing technology has been identified (Spaeth, 1988), but the engineering of a prototype test is still ongoing. The method selected may be used in the site

vertical boreholes study, systematic drilling program, and saturated zone programs or wherever samples from the unsaturated zone are needed.

A series of saturated zone well tests is planned for the existing UE-25 c#1, UE-25c#2, and UE-25c#3 complex of boreholes, using conservative and reactive chemical tracers in single- and multi-well testing schemes. On the basis of the results, single-well saturated zone testing will be extended to existing boreholes distributed across the site area, or a new cluster of saturated zone boreholes (southern tracer complex) may be drilled to the south-southeast of the CPDB at a site to be determined.

Detection and characterization of natural perched water is an important requirement for all surface-based drilling in the vicinity of the site. If perched water is detected during drilling of the multipurpose boreholes, the site vertical boreholes, the systematic drilling program, or saturated zone boreholes in Solitario Canyon, penetration will be suspended so the perched zone can be sampled, tested if appropriate, and isolated from any detrimental effects of continued drilling.

The systematic drilling program is planned in two phases. The first phase is a definite program of 12 boreholes, designed from general statistical principles to obtain areal coverage of the site and to sample small-scale lateral variability. An additional phase of drilling may be appropriate to refine statistical descriptions obtained from the first phase. The attributes of a second phase would depend on the data collected from the first phase and associated activities of the feature-sampling program.

An activity to investigate in situ stress in the Yucca Mountain region calls for hydraulic fracturing stress measurements in several existing boreholes, plus drilling of one or two additional shallow boreholes specifically for stress measurements. The location of such boreholes and the scope of the activity to test existing boreholes have not yet been determined. Also, many of the methods that will be used for geophysical exploration of the site have not been determined. Various methods are proposed for testing and evaluation in Investigation 8.3.1.4.2 (geologic framework of the Yucca Mountain site), and in Study 8.3.1.17.4.7 (subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain).

### 8.4.2.2 Surface-based activities

Surface-based tests consist of geologic, geophysical, hydrologic, geochemical, and other tests and surveys that will be performed both at the land surface and in exploratory boreholes drilled from the surface. Section 8.3.1 describes theses activities in detail. Construction and testing activities are grouped in the following sections according to whether they lie within the conceptual perimeter drift boundary (CPDB), or the conceptual boundary of the controlled area. Rautman et al. (1987) state that the perimeter drift "defines the outer limit of mined openings at waste emplacement depths." The CPDB is thus taken as an outline on the surface directly above the perimeter drift (Figure 8.4.2-1a). The definition of the controlled area used is also

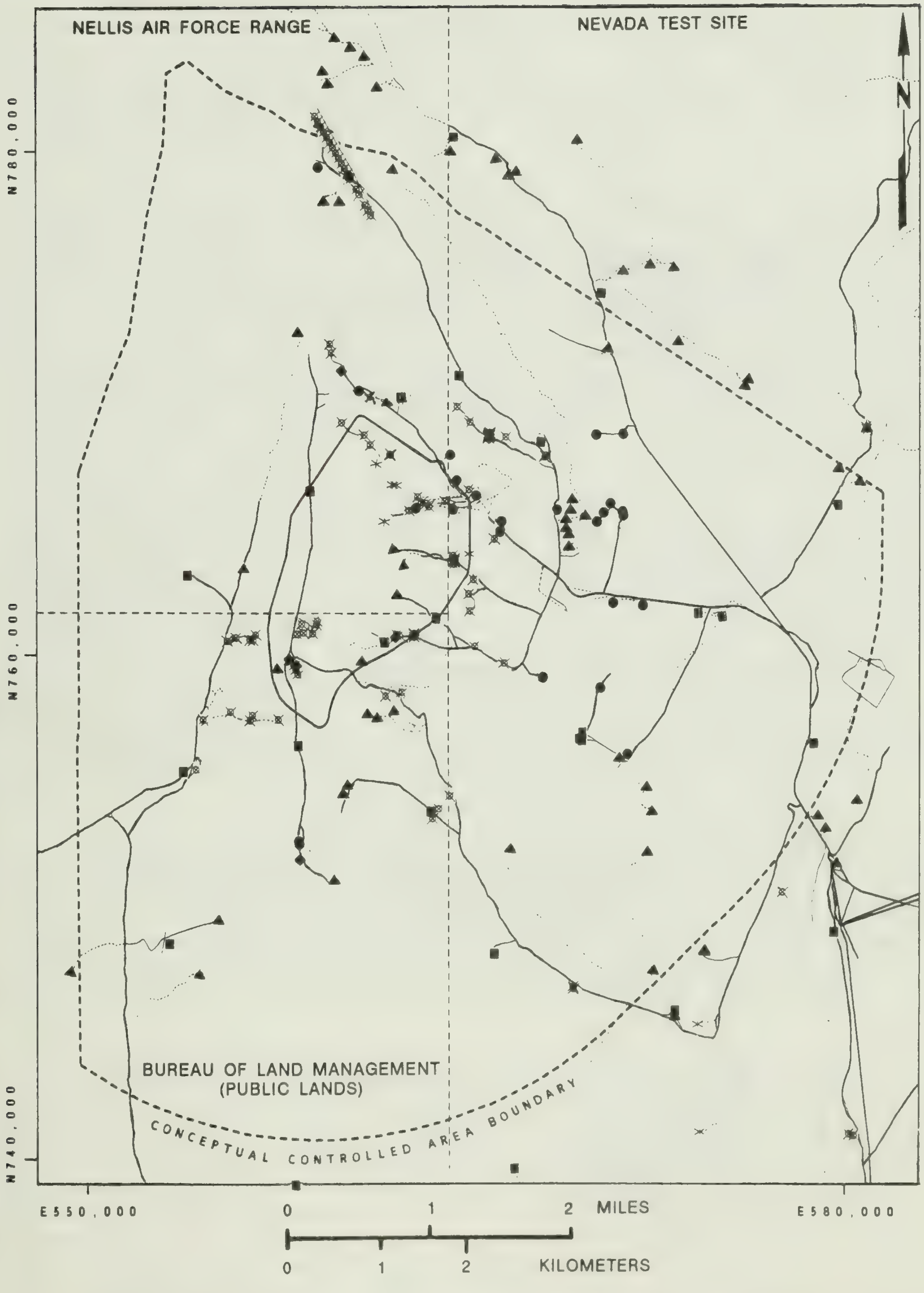


**Figure 8.4.2-1a.** Existing surfaced-based activities. See Figure 8.4.2-1b for legend.

LEGEND

- SHALLOW BORINGS <100FT.
- DRY DRILLHOLES——UNSATURATED ZONE BOREHOLES
- COREHOLES
- SATURATED ZONE AND WATER TABLE BOREHOLES
- TRENCHES
- PAVEMENTS

- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS

- CONCEPTUAL PERIMETER DRIFT BOUNDARY

SOURCES:

1956 1:24,000 USGS TOPOGRAPHIC MAPS
1976 1:24,000 USGS ORTHOPHOTO MAPS
1983 1:100,000 USGS TOPOGRAPHIC MAPS
7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY
GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE
CONCEPTUAL PDB - SNL DRAWING R07003A
MAP COMPILED IN SEPTEMBER 1988

**Figure 8.4.2-1b.** Legend for Figure 8.4.2-1a.

that of Rautman et al. (1987), which includes an area of 100 square kilometers and the subsurface region underlying this area, consistent with 40 CFR Part 191.12(g). The controlled area definition is used in this section only to reference the locations of planned activities, because it is widely published and describes a minimum 2 km distance from the CPDB. Construction controls described in this section are not contingent on the definition of the controlled area.

This section provides site characterization construction and testing activities. Potential environmental effects of surface-based testing have been addressed in Chapter 4 of the final environmental assessment for Yucca Mountain (DOE, 1986b). Site characterization activities are affected by permitting requirements and constraints. The Environmental Regulatory Compliance Plan (DOE, 1987b) describes the plan for complying with applicable regulations and statutes. Applicable permit requirements and constraints are incorporated into surface-based activities (i.e., dust control). If additional permitting requirements are identified, they may modify the design and operation of certain site characterization activities.

All planned field activities exclusive of those associated with the ESF are included in the Project Surface-Based Investigations Plan (SBIP) (DOE, 1988d). The SBIP is a compilation of information on each field activity planned in the SCP, with emphasis on factors affecting environmental and site performance impacts. The SBIP including the following information for each planned activity: references to the SCP and other planning documents; responsible Yucca Mountain Project participants; basic activity information, including type, location, and purpose of the planned activity; relevant technical information (for example, equipment to be used, borehole depths, and survey area descriptions); and anticipated schedule information. The SBIP also includes a summary of planned activities, a general discussion of technical rationale for various activities, and a portfolio of detailed maps showing the locations of planned surface-based testing and construction activities.

The Project Site Atlas is a companion document to the SBIP and contains historical summaries of field studies that have already been performed. The Site Atlas briefly describes each activity and where it was performed. It also contains detailed maps and location information for completed and ongoing activities. Ongoing surface-based testing activities include seismic monitoring, potentiometric-level monitoring, unsaturated-zone hydrologic monitoring, meteorological monitoring, runoff monitoring, and geodetic surveys.

Standard USGS topographic maps were used as the base maps for these two documents. Location data for existing activities were obtained from as-built construction surveys or were provided by the organization responsible for the activity. Locations of planned activities are approximate and were obtained from descriptions in Section 8.3.1, drillhole layout surveys, or from draft study plans. Information sources for each activity are indicated in both documents.

### 8.4.2.2.1 General description of location and extent of testing and construction (existing and planned)

Figures 8.4.2-1a and 8.4.2-2a depict the locations of existing and proposed surface-based field activities. These have been organized by type of surface penetration; drilling-related activities are further organized by drilling methodology and relative depth. Planned trenches are not shown on the figures, because field reconnaissance is needed to locate them accurately. Investigations 8.3.1.5.2 and 8.3.1.17.4 include descriptions of the channel areas and fault zones where this additional trenching is planned. As stated previously, the Project Site Atlas and Surface-Based Investigation Plan contain more detailed maps and location coordinates for existing and proposed activities.

The potential disturbance from existing and planned field activities is summarized in Tables 8.4.2-4 through 8.4.2-6. The first of these tables gives the numbers of existing and planned activities of various types that are located (1) within the CPDB, (2) within the conceptual boundary of the controlled area but outside the CPDB, and (3) outside the controlled area. The table shows that much of the disturbance from existing and planned activities, in terms of numbers of field activities, occurs away from the immediate site area. Tables 8.4.2-5 and 8.4.2-6 give estimates for the amount of area disturbed by pre-site characterization activities and planned surface-based activities, respectively. The estimates are given in terms of acreage for different categories of surface disturbance. The total of existing and planned disturbance to the area within the CPDB is estimated to be 132 acres, or about 10 percent of the area enclosed by the CPDB.

The term "surface disturbance," as used in this section, is defined as (1) activities requiring site preparation where vegetation, surface soils, and possibly even subsoils and bedrock are removed, or (2) activities involving disposition of significant amounts of water at the surface. Most off-road vehicular access, mapping and sampling activities, and surface geophysical surveys are not included in this definition.

Information on water use for planned surface-based testing and construction activities is needed to evaluate test interference and potential site performance impacts. The amounts and locations of planned water use for surface-based testing and construction are described in Section 8.4.2.2.3.

### 8.4.2.2.2 Description of locations, operations, and construction controls for surface-based activities

For implementation of the construction and testing activities required for site characterization, an integration and management control process is planned, as described in Section 8.3.1.4.1 (development of an integrated drilling program and integration of geophysical activities). Baseline control will ensure accountability for significant deviations from specifications and ensure that field changes respect any interdependence among planned activities (e.g., shared use of boreholes). Such control will also ensure that construction or testing controls are based on interference or site-performance impact considerations.

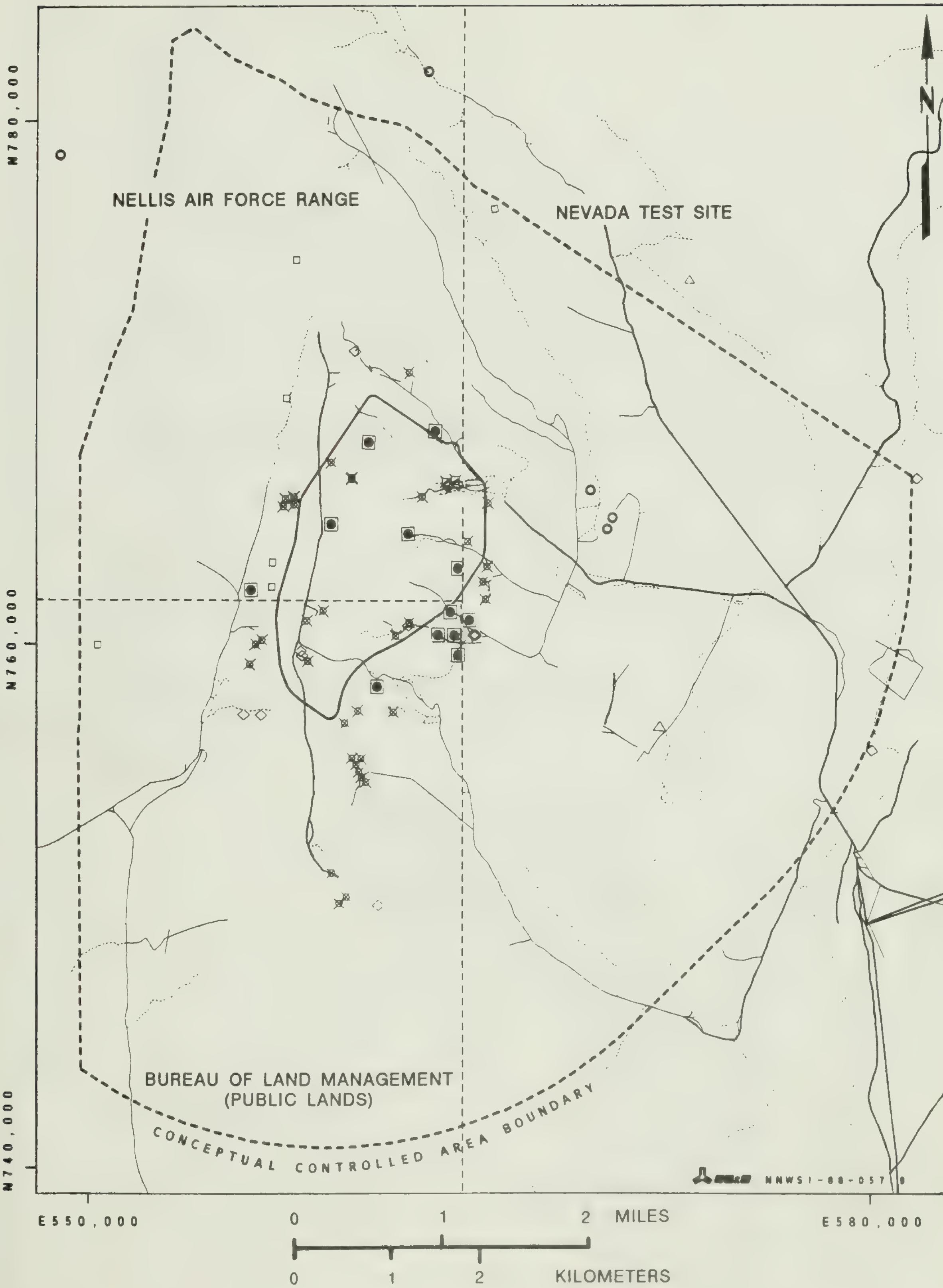


**Figure 8.4.2-2a.** Proposed surface-based field activities See Figure 8.4.2-2b for legend.

## LEGEND

- DRY DRILLHOLES——SHALLOW UNSATURATED ZONE NEUTRON HOLES (<100FT)
- DRY DRILLHOLES——UNSATURATED ZONE BOREHOLES
- SYSTEMATIC DRILLING PROGRAM HOLES
- COREHOLES
- SATURATED ZONE AND WATER TABLE BOREHOLES
- TRENCHES
- EXPLORATORY SHAFTS
- LIGHT DUTY ROADS
- UNIMPROVED ROADS
- TRAILS
- CONCEPTUAL PERIMETER DRIFT BOUNDARY

SOURCES:

1956 1:24,000 USGS TOPOGRAPHIC MAPS
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1983 1:100,000 USGS TOPOGRAPHIC MAPS
7/1986 AND 9/1987 1:24,000 AERIAL PHOTOGRAPHY
GRID TICKS BASED ON NEVADA STATE COORDINATE SYSTEM, CENTRAL ZONE
CONCEPTUAL PDB - SNL DRAWING R07003A
MAP COMPILED IN SEPTEMBER 1988

**Figure 8.4.2-2b.** Legend for Figure 8.4.2-2a.

Table 8.4.2-4. Existing and planned surface-related and drilling-related field activities (page 1 of 3)

| Activity type | Within the conceptual perimeter drift boundary (CPDB)[a] | | Within the controlled area,[b] outside the CPDB | | Outside the controlled area | |
|---|---|---|---|---|---|---|
| | Existing | Planned | Existing | Planned | Existing | Planned |
| Unsaturated-zone boreholes | | | | | | |
| Shallow boring (<100 ft deep) | | | | | | |
| Neutron access holes | 37 | 2 | 36 | 22 | 3 | --[c] |
| Fortymile Wash neutron holes | -- | -- | -- | -- | -- | 10 |
| Large plot rainfall simulation holes (14 sites with 10 holes per site) | -- | 30 | -- | 110 | -- | -- |
| Small plot rainfall simulation holes (23 sites with 4 holes per site) | -- | 32 | -- | 60 | -- | -- |
| Seismic shotholes | -- | -- | 41 | -- | 36 | 21-52 |
| Deep boring | | | | | | |
| Unsaturated zone holes[d] | 4 | 2 | 4 | 7 | -- | -- |
| VSP/UZ prototype hole | -- | -- | -- | 1 | -- | -- |
| Solitario Canyon horizontal hole | -- | -- | -- | 1 | -- | -- |
| Multipurpose boreholes[e] | -- | 2 | -- | -- | -- | -- |
| Systematic drilling program | -- | 5 | -- | 7 | -- | -- |
| Coreholes (drilling mud used as circulation medium to assist in retrieving core) | | | | | | |
| Geologic and exploratory coreholes | 2 | -- | 9 | -- | 4 | 3 |
| Volcanic coreholes | -- | -- | -- | -- | 2 | 4 |
| Surface facility coreholes | -- | -- | 12 | 2 | -- | -- |
| Calcite silica coreholes (5 slant holes and 1 vertical, possible) | -- | -- | -- | 6 | -- | -- |

Table 8.4.2-4. Existing and planned surface-related and drilling-related field activities (page 2 of 3)

| Activity type | Within the conceptual perimeter drift boundary (CPDB) | | Within the controlled area, outside the CPDB | | Outside the controlled area | |
|---|---|---|---|---|---|---|
| | Existing | Planned | Existing | Planned | Existing | Planned |
| Saturated-zone and water-table boreholes | | | | | | |
| Saturated-zone holes | 2 | 1 | 6 | -- | 2 | -- |
| Water-table holes | 1 | -- | 9 | 5 | 6 | 3 |
| Southern tracer complex (depends on test results) | | | -- | 4 | -- | -- |
| In situ stress (1 hole planned, the need for additional drilling depends on test results and possible use of other existing holes) | | | | | -- | 1-22 |
| Trenches[f] | 5 | 1-2 | 33 | ≤17 | 26 | 9 |
| Pavements[g] | 4 | -- | 2 | 2 | -- | -- |
| Roads (linear miles) | | | | | | |
| Unimproved (23 ft wide graded; plus shoulders, drainage ditches, and berms) | 6 | 2 | 37 | 5 | 38 | 13 |
| Trails (single lane, ungraded) | 1.5 | 1 | 21 | 3 | 8 | 1 |
| Other | | | | | | |
| Surface-based testing (proposed) | | | | | | |
| Large plot rainfall simulation sites | | 3 | -- | 11 | -- | -- |
| Small plot rainfall simulation sites | | 8 | -- | 15 | -- | -- |
| Artificial infiltration ponding sites | | 17 | -- | 33 | -- | -- |

Table 8.4.2-4. Existing and planned surface-related and drilling-related field activities (page 3 of 3)

| Activity type | Within the conceptual perimeter drift boundary (CPDB) | | Within the controlled area, outside the CPDB | | Outside the controlled area | |
|---|---|---|---|---|---|---|
| | Existing | Planned | Existing | Planned | Existing | Planned |
| Other (continued) | | | | | | |
| Seismic surveys | See Figures 8.3.2-1 and 8.3.2-2 and maps in the Site Atlas and Surface-based Investigations Plan for locations | | | | | |

[a]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al. (1987)).

[b]Controlled area is the actual area chosen according to the 10 CFR 60.2 definition.

[c]-- = No existing or proposed activities of this type are located in this area.

[d]Five of the existing unsaturated zone boreholes that are less than 500 ft deep will be reentered and drilled to penetrate the water table. These holes include UE-25 UZ#4, UE-25 UZ#5, USW UZ-7, USW UZ-8, and USW UZ-13.

[e]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.

[f]The number of existing trenches does not include the 31 soils investigation trenches that were excavated and reclaimed in Nye Canyon and Silver Lake. Proposed trenches include 1 or 2 trenches along the Ghost Dance fault, which traverse the repository block and controlled area, and 3 or 4 along the Bow Ridge fault and the Solitario Canyon fault that traverse the controlled area. The exact locations of these trenches have not been determined. The proposed numbers of trenches do not include possible trenching at the playas throughout the southern Great Basin (such trenching, if conducted, would be outside the controlled area boundary).

[g]All the planned pavements have not yet been sited. As many as four or more additional pavements may be sited within the CPDB.

Table 8.4.2-5. Extent of existing surface disturbance associated with pre-site-characterization testing (page 1 of 2)

| Type of feature causing disturbance | Acres disturbed within conceptual perimeter drift boundary (CPDB)[a] | Acres disturbed within controlled area,[b] outside of CPDB | Acres disturbed outside the controlled area[c] | Total |
|---|---|---|---|---|
| Roads | | | | |
| Light duty (paved, average width of disturbance 100 ft) | --[d] | 50 | 52 | 102 |
| Unimproved (average width of disturbance 50 ft) | 37 | 224 | 227 | 488 |
| Trails (average width of disturbance 15 ft) | 3 | 38 | 15 | 56 |
| Powerlines | -- | 8 | 42 | 50 |
| Drill pads | 21 | 73 | 24 | 118 |
| Trenches | 1 | 10 | 5 | 16 |
| Pavements | 1 | <1 | -- | 1 |
| Seismic surveys (estimate) | 2 | 20 | 13 | 35 |
| Disturbance associated with drilling neutron access holes | 3 | 3 | -- | 6 |
| Other disturbances (laydown areas, turnarounds, etc.) | 4 | 44 | 10 | 58 |
| Total | 72 | 470 | 388 | 930 |

Table 8.4.2-5. Extent of existing surface disturbance associated with pre-site-characterization testing (page 2 of 2)

Footnotes

[a]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[b]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.

[c]Not all impacts in this area are associated with the Yucca Mountain Project. Many of the existing roads and powerlines in the Fortymile Wash area are associated with Nevada Test Site activities. Several roads that have been constructed in the Bare Mountain, Crater Flat and Amargosa Desert areas were not constructed by the U.S. Department of Energy, nor were they constructed to support the Yucca Mountain Project.

[d]-- = No disturbance is associated with this activity category in this area.

Table 8.4.2-6. Estimates of minimal or potentially significant disturbance (as discussed in Section 8.4.2.2.2.1) associated with planned surface-based testing for site characterization (page 1 of 2)

| Type of feature causing disturbance | Acres disturbed within conceptual perimeter drift boundary (CPDB)[a] | Acres disturbed within controlled area,[b] outside of CPDB | Acres disturbed outside the controlled area | Total |
|---|---|---|---|---|
| Roads | | | | |
| Light duty (paved) | Estimate included with the exploratory shaft facility (ESF)[c] category | | | |
| Unimproved (average width of disturbance 50 ft) | 8 | 30 | 77 | 115 |
| Trails (average width of disturbance 15 ft) | 2 | 6 | 2 | 10 |
| Powerlines | Estimate included with the ESF category | | | |
| Drill pads[d] | 17 | 75 | 28 | 120 |
| Trenches[c] | 1 | 10 | 4 | 15 |
| Pavements | <1 | --[e] | -- | <1 |
| Seismic surveys | 5 | 30 | 35 | 70 |
| Disturbance associated with drilling neutron access holes | 2 | 3 | -- | 5 |
| Other disturbances (laydown areas, turnarounds, etc.)[c] | 5 | 45 | 10 | 60 |
| ESF surface disturbances (laydown areas, turnarounds, etc.)[c] | 20 | 25 | -- | 45 |
| Total | 60 | 224 | 156 | 440 |

Table 8.4.2-6. Estimates of minimal or potentially significant disturbance (as discussed in Section 8.4.2.2.2.1) associated with planned surface-based testing for site characterization (page 2 of 2)

Footnotes

[a]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[b]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.

[c]Estimate based on extent of existing disturbance.

[d]Estimated using 2.5 acres maximum disturbance per drill pad, and with multiple boreholes or several such drill pads.

[e]-- = No disturbance is associated with this activity category in this area.

Plans for surface-based testing do not include the use of high-level radioactive materials or the introduction of radioactive artificial tracers. Radioactive sensors and sources will be used in planned testing, such as borehole geophysical logging, but are designed to be fully contained and retrievable. Any plans to use high-level radioactive materials or to introduce radioactive artificial tracers at the site will be included in SCP progress reports and will be subject to NRC review as specified by 10 CFR 60.18(e).

8.4.2.2.2.1 Site preparation and surface-related activities

Site preparation activities include grading (i.e., access road construction), cut and fill (construction of road cuts, drill pads, and exploratory shaft facility (ESF) support facilities), and excavation (trenches, pits, borrow areas, and pavements).

Activities involving minimal or no disturbance

Many of the data needs for site characterization require measurements at or above the ground surface without invasion of the subsurface. These include meteorological monitoring, radiometric monitoring, geodesy, seismic monitoring, evapotranspiration studies, geologic and surficial deposits mapping, and geophysical surveys (with controls as described below). The methods to be used for these measurements are standard (Section 8.3.1) and so the potential for disturbance is well understood. The following kinds of field activities will be involved:

1. Passive monitoring equipment on the surface or on towers.

2. Construction of survey monuments, small edifices, etc.

3. Geophysical use of noninvasive seismic or electrical sources.

4. Deployment of ground motion detectors or other geophysical instruments.

5. Infrequent off-road vehicular travel.

Surface-related characterization activities producing minimal or no disturbance, as summarized in Table 8.4.2-7, include surface stratigraphic studies, the Southern Great Basin Seismic Network, planned surface geophysical surveys, airborne geophysical surveys, surface stratigraphic studies, soil studies, surface sampling, and meteorological monitoring. Many of these activities are also remote from Yucca Mountain, including debris-flow monitoring, erosion monitoring, surficial-deposits mapping, geomorphic mapping, portable seismic monitoring, and radiological monitoring.

Off-road travel will be required for shallow seismic-reflection studies; for shallow seismic-refraction studies; for other geophysical surveys, such as gravity surveys (Activity 8.3.1.4.2.1.2); and for geologic, geomorphic and surficial-deposits mapping and surface stratigraphic studies (Activities 8.3.1.4.2.2.1, 8.3.1.5.1.4.3, 8.3.1.6.1.1.1, 8.3.1.8.5.1.3, and 8.3.1.16.1.1.1). All these planned activities will use existing roads where

Table 8.4.2-7. Summary of planned surface-related characterization activities in the vicinity of Yucca Mountain--minimal or no disturbance is produced (page 1 of 3)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Borehole, and borehole-to surface geophysical surveys | GSB-YMATL<br>GSB-YMG<br>GSB-YMIPL<br>GSB-YMLSL<br>GSB-YMML<br>GSB-YMPS<br>GSB-YMRE<br>GSB-YMSH | 8.3.1.4.2.1.3 | For definition of lithostratigraphic units and contacts, and the distribution of rock properties within lithostratigraphic units. |
| | GSBB-YM | 8.3.1.4.2.2.5 | Seismic tomography/vertical seismic profiling. |
| Surface geophysical surveys | GSE-YM | 8.3.1.17.4.7.5 | Evaluate surface geoelectric methods. |
| | GSE-YMCFJFADDV<br>GSGI-SWYMIS<br>GSM-SWYMIS<br>CSS-ISSW-1<br>GSS-ISSW-2 | 8.3.1.17.4.3.1 | Deep geophysical surveys in east-west transect crossing Furnace Creek fault zone, Yucca Mountain, and Walker Lane. |
| | GSGI-YM | 8.3.1.17.4.7.2 | Detailed gravity survey. |
| | GSM-YMAM | 8.3.1.17.4.7.3 | Detailed aeromagnetic survey of site area. |
| | GSM-YMGM | 8.3.1.17.4.7.4 | Detailed ground magnetic survey of specific features. |

Table 8.4.2-7. Summary of planned surface-related characterization activities in the vicinity of Yucca Mountain--minimal or no disturbance is produced (page 2 of 3)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Surface geophysical surveys (continued) | GSP-S | 8.3.1.4.2.1.5 | Magnetic property data for stratigraphic correlations and structural interpretations. |
| | GSS-YMCFJF | 8.3.1.17.4.7.8 and others | Evaluate shallow seismic reflection (mini-sosie) methods and if appropriate, conduct surveys of selected structures at and near Yucca Mountain. |
| | GSRRS-YM | 8.3.1.17.4.7.6 | Evaluation and possible application of methods to detect buried faults using gamma measurements. |
| | GBSRRS-YMM | 8.3.1.17.4.7.7 | Evaluation and possible application of thermal infrared methods for surface hydrologic and faulting characteristics. |
| | GSP-YMR | 8.3.1.17.4.3.2 | Evaluate Quaternary faults within 100 km of Yucca Mountain, of remote sensing and surface investigation techniques. |
| | GSS-SR | 8.3.1.17.4.4.3 | Evaluate Stagecoach Road fault system. |
| Engineering properties measurement | GSS-VSF | 8.3.1.14.2.3.3 | Measure in situ soil and rock properties; profile alluvium-bedrock contact; locate discontinuities or abnormalities; and characterize soil and rock stratigraphic units. |

Table 8.4.2-7. Summary of planned surface-related characterization activities in the vicinity of Yucca Mountain--minimal or no disturbance is produced (page 3 of 3)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Structural and stratigraphic studies | Geologic mapping and soil studies | 8.3.1.4.2.1.1<br>8.3.1.4.2.2.1<br>8.3.1.5.1.4.2 | Geologic and surficial deposits mapping; soil sampling. |
| | GSB-YMCL | 8.3.1.4.2.1.1 | Surface and borehole stratigraphic studies of host rock and surrounding units. |
| Southern Great Basin Seismic Network | (b) | 8.3.1.17.4.1.2 | 54-station short period, multicomponent telemetered network; 6 stations at Yucca Mountain. |
| Geodetic survey | (b) | 8.3.1.17.4.10 | Level lines and quadrilateral array surveyed biannually; global positioning satellite stations resurveyed periodically. |
| Meteorological monitoring | (b) | 8.3.1.12.2.1.1 | Five monitoring stations located on towers in the immediate vicinity of Yucca Mountain. |

[a]SBIP = Surface-Based Investigations Plan (DOE, 1988d). (See text for further discussion of plan.)
[b]Ongoing activities; not included in Surface-Based Investigations Plan.

possible; no new roads will be constructed for these activities. Off-road vehicular travel will be coordinated among these activities to the extent practicable. For geophysical methods that may be introduced in the future, or for which analysis is required before application, the extent of surface disturbance and the potential impacts to site performance will be evaluated before implementation. For example, the surface disturbance and potential impacts from intermediate depth (2 to 3 km) seismic reflection and refraction will be evaluated when the objectives and methods for these surveys are determined.

Activities involving potentially significant disturbance

Surface-related activities involving potentially significant surface disturbances are summarized in Table 8.4.2-8. Site performance impacts for this group are evaluated in Section 8.4.4. The group includes natural and artificial infiltration studies, trenching of faulted surface deposits, trenches or pits for soil and debris sampling, and surface fracture network ("pavement") studies. Some activities in Table 8.4.2-8 are generally remote from Yucca Mountain, specifically the regional potentiometric-level, evapotranspiration, and hydrochemistry studies; paleoclimate studies; paleoecology studies; and paleohydrology studies. The following paragraphs describe these surface-related activities involving surface disturbance, explain their locations, and discuss the associated construction controls. Roads and drill pads are also discussed, because they involve similar types of disturbances.

Roads

Two types of roads exist at or near the site, exclusive of the ESF: bladed, unimproved dirt roads, and one-lane dirt tracks or trails. Bladed roads generally are required where the amount of vehicular traffic is significant or where heavy vehicles and equipment must have access, such as many of the borehole sites. Unimproved dirt tracks or trails may be required for bulldozer and four-wheel-drive access to trenching, pavement, and infiltration study locations. To minimize the impact of roads on infiltration, each new road will be improved to the minimum extent necessary and maintained appropriately. Special measures, such as installing tile drains and culverts, may be taken to reduce alteration of surface runoff patterns. The linear extent of existing and new roads within the CPDB, within the conceptual boundary of the controlled area, and outside the controlled area are estimated in Table 8.4.2-4. Standard Nevada Test Site road construction specifications and maintenance requirements have been used for existing roads; these roads have been consistently maintained since they were constructed.

In general, bladed, unimproved dirt roads are surveyed before construction. Where the road is cut into a slope, the removed material is cast off to create soft shoulders. Such roads are constructed so that minimal maintenance is necessary; this requires that water be prevented from flowing down the road surface for any significant distance. Accordingly, these roads are usually not crowned or super-elevated (banked); semicircles of 12 in. pipe or speed-bumps may be installed in the road to divert water to the side, and culverts are installed where the road crosses a drainage. Depending on the

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 1 of 4)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Streamflow/runoff and precipitation monitoring | P1 through P4<br>S1 through S24 | 8.3.1.2.1.2.1 | Monitor precipitation and runoff to determine runoff component of hydrologic cycle for unsaturated zone investigations. |
| Natural infiltration studies; data collection | Neutron access holes | 8.3.1.2.2.1.2 | Neutron moisture logging in unsaturated zone. Geophysical logging of 74 existing and 25 additional planned holes. |
| Natural infiltration studies; new drilling | N11<br>N15 through N17<br>N16<br>N27<br>N31 through N39<br>N46<br>N53<br>N53a<br>N54<br>N57 through N59<br>N61 through N64 | 8.3.1.2.2.1.2 | Neutron moisture logging in unsaturated zone. (24) shallow holes up to approximately 100 ft deep. |
| Artificial infiltration studies, new drilling | LPRS 1A, ..., 1J<br>.<br>.<br>.<br>14A, ..., 14J<br>.<br>.<br>. | 8.3.1.2.2.1.3 | Large-plot and small-plot rainfall simulation rainfall simulation experiments.<br>(10) shallow holes at each 14 locations.<br>(4) shallow holes at each of 23 locations. |

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 2 of 4)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Artificial infiltration studies, new drilling (continued) | SPRS 1A, ..., 1D . . . 23A, ..., 23D | | |
| Artificial infiltration studies; construction and testing | LPRS 1A, ..., 1J . . 14A, ..., 14J | 8.3.1.2.2.1.3 | Large-plot and small-plot rainfall simulation experiments; ponding and rainfall simulation experiments; see text. |
| | SPRS 1A, ..., 1J . . . 23A, ..., 23D | | |
| Natural infiltration monitoring; saturated zone recharge studies | FMN #1 through FMN #10 | 8.3.1.2.1.3.3 | Monitor infiltration into Fortymile Wash using geophysical logs. Shallow holes, located near the conceptual boundary of the controlled area.[b] |
| Faulting studies | Mid Valley 2a through 2d | 8.3.1.17.4.2.1<br>8.3.1.17.4.2.2 | Locate, excavate, and map one or more trenches at the conceptual location of the repository surface facilities. Located >1 km from conceptual perimeter drift boundary.[c] |
| | Paleohydrology | 8.3.1.5.2.1.5 | Investigate origin of calcite and opaline silica deposits. |

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 3 of 4)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Faulting studies (continued) | Stagecoach Road 1 & 2 | 8.3.1.17.4.4.3 | Evaluate magnitude and nature of Quaternary movement on Stagecoach Road fault system. Located near conceptual boundary of controlled area. |
| | Yucca Mountain 1 & 2 | 8.3.1.17.4.6.2 | Evaluate magnitude and nature of Quaternary fault movement in vicinity of Bow Ridge. |
| | Yucca Mountain 3 through 8 | 8.3.1.17.4.6.2 | Evaluate magnitude and nature of Quaternary fault movement in vicinity of Busted Butte. |
| Vein deposits investigation | Trench 14 | 8.3.1.5.2.1.5 | Deepen existing trench(s); investigate origin of calcite and opaline silica deposits. |
| Surface fracture network studies | Pavement studies | 8.3.1.4.2.2.2 | Clean unconsolidated material from outcrop surfaces for mapping. Outside conceptual perimeter drift boundary and close to controlled area boundary. |
| | | 8.3.1.5.2.1.3 | Mapping, sampling, and geophysical activities throughout Amargosa Valley -- Death Valley ground-water system. |
| Terrestrial paleoecology studies | | 8.3.1.5.1.3 | Sampling and analysis of pollen and midden materials from throughout the Yucca Mountain region. |
| Analog recharge studies | | 8.3.1.5.2.1.4 | Soil hydrology studies at Pahute Mesa, Topopah, and other locations. |

Table 8.4.2-8. Summary of planned surface-related characterization activities that could produce potentially significant disturbance in the vicinity of Yucca Mountain (page 4 of 4)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Paleoclimate study of Lake, Playa, and Marsh deposits | | 8.3.1.5.1.2 | Sampling activities at location throughout the Great Basin. |
| Regional aquifer potentiometric, evapotranspiration and hydrochemistry studies | | 8.3.1.2.1.3<br>8.3.11.2.1.3 | Various sampling and monitoring activities throughout the Amargosa Valley -- Death Valley ground-water system. |
| Regional paleoflood evaluation | | 8.3.1.5.2.1.1 | Trenching in water courses of Yucca Mountain and vicinity. |

[a]SBIP = Surface-Based Investigations Plan (DOE, 1988d).

[b]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[c]Controlled is the actual area chosen according to the 40 CFR 191.12(g) definition.

amount and type of use, road maintenance involves blading and filling to level ruts after a storm, and watering for dust suppression.

Water will probably be sprayed on unpaved access roads to control dust. This is the most commonly used method of dust control at construction and mining sites and is the method that has been used at Yucca Mountain and at the Nevada Test Site. It is difficult to accurately estimate the water that will be used for this purpose before site characterization, or to predict future use of water for dust control, because of the varying environmental, traffic, and road conditions. On the basis of previous experience at Yucca Mountain, however, the equivalent of one water truck is expected to deliver approximately 600,000 gallons per month to the site on a seasonal basis for dust control during site characterization. This figure is based on one 5,000-gallon water truck making six trips per day between the water supply well (J-13) and the site area during a 5-day work week. A water truck averages about 10 mph while spraying; with spray time of 30 minutes, a 27-ft-wide road surface receives approximately 1.4 mm of water. When three drill rigs are active during site characterization, this water truck will cover the access roads at least twice a day, resulting in at least 2.8 mm per day of water applied to the road surface. Of the approximately 120 miles of existing and planned unpaved access roads that could be watered during site characterization, fewer than 8 miles will be located within the CPDB. Of the approximately 1,420 acres of surface area within the CPDB, about 26 acres (or less than 2 percent of the surface area) will receive this additional water.

In general, one-lane dirt tracks or trails will not be bladed. These roads will be constructed where necessary for access to construction or intermittent data collection. For the infiltration studies, including natural infiltration monitoring, rainfall simulation, and ponding studies, the shortest distance to a road or trail that is passable to semitrailer transport must not exceed 200 ft. For the infiltration studies, roads and trails will be located to approach the experiments but maintain a reasonable distance to avoid interfering with the measured processes.

Drill pads

Deep drilling will require construction of level, compacted dirt drill pads, which will include area for parking and equipment storage. For boreholes drilled in the controlled area with fluid, a lined pit will be constructed on the pad for discharge of any recovered drilling fluid and cuttings. Boreholes drilled outside the controlled area may be lined, as conditions warrant. Present plans for additional boreholes are summarized in Table 8.4.2-4. In some cases, such as planned boreholes USW UZ-2 and USW UZ-3, more than one deep borehole will be drilled at a single site, thus reducing the extent of necessary surface preparation. Pad size will be minimized to the extent practicable; the actual size will be determined on a location-specific basis, and will depend on the method of drilling, type of drill rig, etc. Because each pad will be level and compacted, moderate precipitation will result in puddling, and subsequent evaporation and possible runoff. The effects of this type of surface disturbance on planned testing are discussed in Section 8.4.2.2.3. Fluid components of drilling fluid residue will be allowed to evaporate from the discharge pits. Pits will be backfilled, compacted, and reclaimed after drilling is complete. Materials such as bentonite and polymer or detergent residues will thus be

buried in lined pits at the drill site where they are used. Special procedures will be developed to dispose of other types of residue, if other types of drilling fluids are used.

Trenches

Trenching activities are needed for tectonic studies of faults and fault zones (Studies 8.3.1.17.4.3 and 8.3.1.17.4.4) and for paleohydrology studies (Activities 8.3.1.5.2.1.1 and 8.3.1.5.2.1.5). Trenches and test pits will be excavated by bulldozers or articulated shovels. The material removed during excavation will be stored at the surface next to each trench and will be controlled in such a way as to minimize channeling of runoff from the surrounding area into the trench. Trenches that are oriented approximately parallel to slope gradient will be constructed where practicable, so that water in the trench can drain back to grade at the lower end to reduce puddling. Existing trenches within the CPDB were excavated on slopes parallel to gradient, including those excavated to study the Ghost Dance, Abandoned Wash imbricate, and Solitario Canyon fault zones. Planned trenches will be similarly situated and constructed where practicable. After completion of studies in the trenches, they will be refilled and compacted using the originally removed material.

Approximately 26 new trenches are planned for tectonic studies in the Yucca Mountain region, at features including the Bare Mountain fault zone (Activity 8.3.1.17.4.3.4), the Mine Mountain fault system (Activity 8.3.1.17.4.4.2), the Stagecoach Road fault zone (Activity 8.3.1.17.4.4.3), the Cane Spring fault system (Activity 8.3.1.17.4.4.4), the Paintbrush Canyon fault (Activity 8.3.1.17.4.6.2), the Bow Ridge fault (Activity 8.3.1.17.4.6.2), the Windy Wash fault zone (Activity 8.3.1.17.4.6.2), the Ghost Dance fault (Activity 8.3.1.17.4.6.2), the Solitario Canyon fault (Activity 8.3.1.17.4.6.2), and the proposed location of the repository surface facilities in Midway Valley (Study 8.3.1.17.4.2). Trench depths will range from 10 to 20 ft, widths will be 10 to 16 ft, and lengths will be up to 1,000 ft. Planned trenches within the CPDB or immediate vicinity will be approximately 100 ft or less in length; the longest trenches will be in Midway Valley, about one mile east of the CPDB. Trenches longer than about 100 ft may be excavated as a series of 100- to 200-ft long trenches that are parallel but offset in both the transverse and longitudinal directions to facilitate excavation.

For the calcite-silica studies, Trench 14 will be deepened and widened for half its length and one new trench will be excavated 10 ft deep, 13 ft wide, and about 66 ft long. Of the planned trenches, one or two will be located within the CPDB, 16 or 17 within the controlled area, and 9 outside the controlled area boundary (Table 8.4.2-4). Field reconnaissance will be necessary to determine the exact locations of proposed trenches. Several soil pits up to 5 ft deep and requiring mechanized digging equipment are planned in conjunction with surface mapping (Activities 8.3.1.4.2.2.1 and 8.3.1.5.1.2.2); these will be refilled immediately after use.

Pavements

In this context, the term "pavement" refers to a bedrock surface that has little or no regolith covering; pavements are uneven natural surfaces and

are commonly located on slopes. Pavement studies involve mapping and measurement of fracture patterns in bedrock. The objective of these studies is to provide fracture information for evaluating the geomechanical response of stratigraphic units at the site and for hydrologic modeling, as described in Activity 8.3.1.4.2.2.2. Planned pavement studies will be undertaken only where bedrock is relatively close to the surface. In some instances, clearing of thin layers of surficial material may be required to expose a sufficient amount of bedrock (up to 800 $m^2$ of cleared area is needed per pavement, depending on the geologic aspects of each pavement location). Where necessary, bedrock will be cleared by spraying water under moderate pressure on the surface. Water for this purpose will be hauled to the site by truck. Displaced surface material will collect adjacent to the cleared area. Water is expected to puddle on the uneven bedrock surface, run into fractures, and possibly run off into nearby drainages. Currently, four pavements exist within the CPDB and two pavements within the controlled area. A comparable number of additional pavements in similar locations is planned.

Seismic shotholes

Boreholes have been drilled to depths of 15 to 60 m (50 to 200 ft) for use as shotholes in previous seismic surveys. A north-south linear array of 20 boreholes was drilled north of the site area for a reflection survey (McGovern et al., 1985), and an east-west line of 21 boreholes was drilled east of the site area for seismic refraction (Sutton, 1985; F&S, 1987a). In addition, some boreholes (approximately 36) were drilled regionally for refraction experiments. For seismic reflection, the boreholes were used to place small charges (e.g., 10 lb of dynamite), whereas for the refraction experiments larger charges (up to 4,000 lb of ammonium nitrate) were used. In each instance, measures were taken before shooting, such as stemming to the surface with gravel to minimize surface disturbance.

Plans for seismic exploration in Section 8.3.1.17 are categorized according to the depth of the objective horizons: shallow, intermediate, or deep. Shotholes are not planned for shallow seismic surveys. The methods to be used for intermediate and deep work are contingent on feasibility studies conducted away from the site area (Activities 8.3.1.17.4.3.1 and 8.3.1.17.4.7.1), and on a decision to proceed (Section 8.4.2.1.4). If seismic surveys across the immediate site area are proposed that involve the use of shothole explosive sources, then the associated impacts to other tests or to site performance will be considered in the decision to proceed. At present, no shotholes have been drilled or used within the CPDB, nor are any planned.

Natural infiltration studies

The main purpose of the shallow infiltration studies is to define the upper flux-boundary conditions for Yucca Mountain during both present and simulated wetter-climatic conditions. Knowledge of flux-boundary conditions is necessary to model flow through the thick unsaturated zone beneath Yucca Mountain. Field studies will be confined mainly to the upper 30 ft of surficial rock and alluvium. However, some activities may extend to 100 ft in the deepest of the neutron-access boreholes.

The neutron-access boreholes (for use of neutron moisture probes and crosshole gamma probes) are a principal aspect of infiltration studies at the site. Currently, 74 neutron-access boreholes exist in the vicinity of Yucca Mountain, in which moisture logging has been conducted since July 1984. The boreholes were drilled dry and cased using the ODEX system with air circulation. For this application, the ODEX 115 system (nominal 15-cm borehole diameter) was mounted on an all-terrain, rubber-tired carrier system to minimize the nature and extent of surface disturbance. An air hose connected the drilling apparatus to a compressor located up to 200 ft away, where there was road or trail access suitable for delivery of drill and compressor. The boreholes were drilled and cased simultaneously, and at the conclusion of drilling a small amount of cementitious grout was applied around the casing at the ground surface to inhibit infiltration through the annulus. In addition, an operable steel closure was welded to the top of the casing, which remains closed except during periodic logging operations. The boreholes constructed in this manner will continue to be monitored during site characterization (Activity 8.3.1.2.2.1.2).

An additional 24 neutron-access boreholes are planned using this same method. Using existing roads will eliminate the need to construct additional improved roads within the CPDB or immediate vicinity for Activity 8.3.1.2.2.1.2. The proposed locations for the new boreholes are approximate. As construction proceeds, the need will arise for some one-lane trails to provide access for construction, testing, and periodic data collection. In general, these access routes will not be bladed and will approach the infiltration experiment locations so as not to interfere with the measured processes.

Initially, neutron-access boreholes were located with respect to two broad hydrogeologic-surficial classifications: alluvium-colluvium in canyon bottoms, and upland bedrock typically covered by a thin layer of unconsolidated material. The first 46 boreholes were drilled at distributed locations that sampled both of these classifications. Evaluation of collected data indicated that different stratigraphic units in upland bedrock locations exhibit different infiltration characteristics. The properties probably are related to fracture densities in the various units, so the hydrogeologic-surficial units in upland areas were redefined according to the geologic subunits defined by Scott and Bonk (1984). Since then, these criteria have been used to site an additional 28 neutron-access boreholes. Planned drillholes will be sited in different topographic settings within each hydrogeologic unit. These various locations will be used to examine the effects of soil thickness on infiltration within different units. Of the neutron-access boreholes drilled in lower canyons with alluvial-colluvial deposits, some were along traverses perpendicular to the canyon axis to examine the effects on infiltration of the thickness of the deposits, proximity to the canyon walls, and proximity to the center of the most recently formed channels. Other boreholes were sited along traverses parallel to the main canyon axis to study the effects of increased drainage area.

A secondary use of the neutron-access boreholes is in the artificial-infiltration studies (Activity 8.3.1.2.2.1.3). Neutron moisture logging will be used with other monitoring techniques for ponding experiments. These experiments will also be conducted in the various hydrogeologic units and

topographic settings to estimate hydraulic conductivity as a function of water content.

Artificial infiltration experiments

A series of four different types of infiltration experiments is proposed in Activity 8.3.1.2.2.1.3: double-ring infiltrometer measurements, ponding studies, small-plot rainfall simulation studies, and large-plot rainfall simulation studies. These studies are successively more complex and involve increasing amounts of water. The double-ring infiltrometry studies will be used in the vicinity of existing neutron-access boreholes in various surficial geologic settings to characterize infiltration rates at a small scale within approximately the upper foot of surficial material. Drilling is not required, and insignificant amounts of water are involved.

Ponding studies will be conducted at the sites of existing neutron-access boreholes, which will be used to monitor moisture influx during the tests. A low berm will be constructed of impervious material around a preexisting borehole or pair of holes, enclosing about 100 $ft^2$. A dye tracer will be mixed with the ponded water to indicate pathways, and the water will be tagged with an appropriate chemical tracer. The total water use will not be more than about 20,000 gallons per location, and may be less, depending on the rate of wetting front advancement. The rock mass beneath some highly fractured locations may be excavated to a depth of as much as 25 ft following ponding, and flow pathways will be mapped from tracer indications. As many as six such deep openings will be constructed using mining methods. Shallower excavations will be constructed at the other ponding locations, using surface excavation methods similar to trenching. At the conclusion of mapping and related studies at each location, the excavation will immediately be backfilled and compacted.

The small plot rainfall simulation studies will measure unsaturated hydraulic conductivity and other flow parameters in approximately the upper one meter. The plots will be about 10 $ft^2$, and will be instrumented to detect and sample moisture, measure moisture potential, and measure surface runoff. At each small-plot site, an array of approximately four shallow (5-ft) monitoring boreholes will be drilled dry and instrumented. A water distribution system similar to irrigation systems will be used to simulate discrete rainfall events. Plans call for several tests at each site, with each test to involve up to a few hundred gallons of water. Specific parameters for these tests have not been determined, and may also be varied during the field program. The water used will contain a dye tracer for infiltration detection and monitoring, and will be tagged with an appropriate chemical tracer. A control plot will be located adjacent to each small plot rainfall simulation test plot in an equivalent hydrogeologic setting. Control plots will be similarly instrumented but will receive only natural rainfall.

After completion of the small plot rainfall simulation studies, more complex large plot rainfall simulation studies will be conducted at several locations that represent the range of surficial conditions affecting infiltration. At each site, an array of deeper monitoring boreholes (10 to 50 ft deep) will be drilled dry and instrumented. Surface instrumentation will also be used to monitor water distribution, evapotranspiration, and runoff. Water will be distributed over an area of about 100 to 300 $ft^2$;

several tests will be conducted at each location, each involving a few thousand gallons of water. After the subsurface region is sufficiently wet, the subsurface drainage of the region will be monitored.

### 8.4.2.2.2.2 Drilling-related activities

Drilling-related activities are summarized in Table 8.4.2-9. These include testing and sampling activities, and many activities that are relatively remote from the site. The following descriptions emphasize activities located in the site vicinity.

Unsaturated-zone boreholes, the multipurpose borehole activity, and the systematic drilling program

The unsaturated-zone drilling program (Activity 8.3.1.2.2.3.2, site vertical boreholes study), the multipurpose-borehole testing activity (Activity 8.3.1.2.2.4.9), and the systematic drilling program (Activity 8.3.1.4.3.1.1) involve similar drilling methods, sampling requirements, and technical objectives. Each of these activities will provide detailed information on hydrologic properties, moisture content, and moisture potential in the unsaturated zone. Drilling and coring will be performed dry to minimize contamination of samples, and (in support of monitoring applications associated with the unsaturated zone holes and the proposed multipurpose borehole activity) to reduce disturbance to the in situ hydrologic conditions.

Samples and information collected by the site vertical boreholes study and the systematic drilling program will be of sufficient distribution and quality for characterization of the vertical variability of matrix saturation and unsaturated matrix flow properties at each borehole location. In this respect, the three activities are basically equivalent. After drilling, the site vertical boreholes and the multipurpose boreholes will be tested and the site vertical boreholes will be instrumented, whereas the boreholes of the systematic drilling program will be shut in and maintained for possible future use.

Integration of vertical boreholes with the repository layout will be undertaken using an approach based on sealing concepts. Each borehole will be located, to the extent practicable given the preliminary nature of the repository design, in an unexcavated pillar in the underground facility with a minimum separation from the nearest drift opening or waste container. Separation ensures that once a seal is installed, it responds to environmental changes in the rock mass (e.g., temperature and stress changes) but is undisturbed by the associated effects of nearby openings (e.g., stress concentration). This integration strategy relies on the design flexibility called for by 10 CFR 60.133(b), while providing the planning and coordination stipulated in 10 CFR 60.15(d)(4).

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 1 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Site vertical boreholes; drilling | USW UZ-2<br>USW US-3<br>USW UZ-9<br>USW UZ-9a<br>USW UZ-9b<br>USW UZ-10<br>USW UZ-11<br>USW UZ-12<br>USW UZ-14 | 8.3.1.2.2.3.2 | For site vertical borehole studies. Drill dry to the water table; sampling plans integrated with with drilling program. |
| | UE-25 UZ#4<br>UE-25 UZ#5<br>USW UZ-7<br>USW UZ-8<br>USW UZ-13 | 8.3.1.2.2.7.1 | For site vertical borehole studies. Deepen to water table using dry drilling methods; sampling plans integrated with systematic drilling program. |
| Vertical seismic profile support and unsaturated zone (UZ) prototype | UE-25 VSP#1 | 8.3.1.4.2.2.5 | Investigate the potential for vertical seismic profiling techniques as a means for broadly detecting and characterizing the subsurface fracture network. Provide a prototype hole to test dry drilling and coring. |
| Multipurpose boreholes, drilling[b] | USW MP-1<br>USW MP-2 | 8.3.1.2.2.4.9 | If feasible, to sample baseline condition before shaft construction, and monitor disturbance during construction. Drilled dry; each to penetrate only to depth of shaft. |
| Saturated zone recharge studies; drilling | UE-25 FM #1 - #3 | 8.3.1.2.1.3.3 | Infiltration measurements for Fortymile Wash recharge study. Near conceptual boundary of controlled area.[c] |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 2 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Water table studies; drilling | USW WT-8 | 8.3.1.2.3.1.2 | Study of saturated zone in vicinity of Solitario Canyon fault. Drilled dry through the UZ. |
| | UE-25 WT#19<br>UE-25 WT#20<br>USW WT-21<br>USW WT-22 | 8.3.1.2.3.1.2 | Investigate potentiometric levels east of repository site. Located >1 km from conceptual perimeter drift boundary.[d] |
| | USW WT-9 | 8.3.1.2.3.1.1<br>8.3.1.2.3.1.2 | Study of saturated zone in vicinity of Solitario Canyon fault. Drilled dry through UZ. |
| | USW WT-23<br>USW WT-24 | 8.3.1.2.3.1.2<br>8.3.1.2.1.3.2 | Investigate the nature of potentiometric gradient to the north of the site. |
| Solitario Canyon fault study in the saturated zone; drilling | USW H-7 | 8.3.1.2.2.1.2 | Study of hydrologic character of Solitario Canyon fault zone. Drilled dry through the unsaturated zone. |
| Multiwell tracer tests; drilling | STC #1<br>STC #2<br>STC #3<br>STC #4 | 8.3.1.2.3.1.8 | Multiple well tests with conservative tracers; may be drilled if single well tracer tests at the C-well complex are unsuccessful. |
| Geologic coreholes; drilling | USW G-5<br>USW G-6<br>USW G-7 | 8.3.1.4.2.1.1<br>8.3.1.17.4.8.2<br>8.3.1.2.3.2.2 | Correlate lithology changes with changes in potentiometric surface (G-5); provide sub-surface stratigraphic control for water table gradient north of Yucca Mountain in |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 3 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Geologic coreholes; drilling (continued) | | | vicinity of Windy Wash (G-6); and check on lapping of Topopah Spring tuff onto paleo-high in Crater Flat tuff and correlate to regional ground-water flow, possibly intercepting Paleozoic-Tertiary contact (USW G-7). The three holes are located outside conceptual boundary of controlled area. |
| Vein deposits study; drilling | UE-25 PH #1A1<br>UE-25 PH #1A2<br>UE-25 PH #1A3<br>UE-25 PH #1A4<br>UE-25 PH #1A5 | 8.3.1.5.2.1.5 | Investigate depth extent, configuration of calcite/silica vein deposits, in the vicinity of Trench 14. |
| Systematic drilling program | USW SD-1<br>USW SD-2<br>USW SD-3<br>USW SD-4<br>USW SD-5<br>USW SD-6<br>USW SD-7<br>USW SD-8<br>UE-25 SD-9<br>USW SD-10<br>USW SD-11<br>USW SD-12 | 8.3.1.4.3.1.1 | Characterize matrix saturation and flow properties, fracture properties, geochemistry, and geochemical properties. |
| Conceptual repository surface facilities site; exploratory drilling | UE-25 RF#1<br>UE-25 RF#2 | 8.3.1.14.2.1.3 | Geophysical measurements of dynamic soil properties to support engineering design/environmental hazard assessment. |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 4 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Solitario Canyon horizontal borehole | (e) | 8.3.1.2.2.3.3 | Conceptual plan for dry drilled penetration into Topopah Spring Member, from scarp. Depends on feasibility of drilling, sealing. |
| Site vertical bore-holes; testing | USW UZ-1<br>USW UZ-2<br>USW UZ-3<br>UE-25 UZ#4<br>UE-25 UZ#5<br>USW UZ-7<br>USW UZ-8<br>USW UZ-9<br>USW UZ-9a<br>USW UZ-9b<br>USW UZ-10<br>USW UZ-11<br>USW UZ-12<br>USW UZ-13<br>USW UZ-14 | 8.3.1.2.2.3.2 | Pneumatic testing, logging, instrumentation, stemming, and monitoring of dry-drilled holes that penetrate to the water table. |
| | USW UZ-1<br>USW UZ-2<br>USW UZ-3<br>UE-25 UZ#4<br>USW UZ-7<br>USW UZ-8<br>USW UZ-9<br>USW UZ-10<br>USW UZ-14 | 8.3.1.2.2.7.1 | Measure gas composition in unsaturated zone. |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 5 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Site vertical boreholes; testing (continued) | UE-25 UZ#5<br>USW UZ-6<br>USW UZ-6a<br>USW UZ-13 | 8.3.1.2.2.6.1,<br>8.3.1.2.2.6.1 | Measure gas circulation and gas composition in unsaturated zone. |
| Vertical seismic profile support and unsaturated zone prototype | UE-25 VSP#1 | 8.3.1.4.2.2.5 | Investigate the potential for vertical seismic profiling techniques as a means for broadly detecting and characterizing the subsurface fracture network. Provide a prototype hole to test dry drilliing and coring. |
| Multipurpose boreholes;[b] testing | USW UZ-11<br>USW UZ-12 | 8.3.1.2.2.6.1 | Measure gas circulation in unsaturated zone. |
| | USW MP-1<br>USW MP-2 | 8.3.1.2.2.4.9 | Periodic logging and pneumatic packer testing during shaft construction. |
| Saturated zone single-well tracer testing | UE-25 C#1<br>UE-25 C#2<br>UE-25 C#3 | 8.3.1.2.3.1.4<br>8.3.1.2.3.1.5<br>8.3.1.2.3.1.7 | Flow testing of C-hole complex using conservative and reactive tracers. Chemical tracers only. |
| | STC #1<br>STC #2<br>STC #3<br>STC #4 | 8.3.1.2.3.1.6<br>8.3.1.2.3.1.8 | Multiple well tests with conservative and reactive tracers; conducted if single well tracer tests at C-well complex prove unsuccessful. |
| | UE-25 A#1<br>UE-25 B#1<br>USW G-4 | 8.3.1.2.3.1.6<br>8.3.1.2.3.2.2 | Well testing with conservative tracers, to be conducted if single-well tests at the C-well complex prove successful. |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 6 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description |
|---|---|---|---|
| Saturated zone single-well tracer testing (continued) | USW H-1<br>USW H-3<br>USW H-4<br>USW H-5<br>USW H-6 | 8.3.1.2.3.2.2<br>8.3.1.2.3.1.8 | Well testing with conservative tracers, to be conducted if single-well tests at the C-well complex prove successful. |
| Solitario Canyon fault Study in the saturated zone | USW H-6<br>USW H-7<br>USW WT-8<br>USW WT-9 | 8.3.1.2.2.1.2 | Cross-hole testing between USW H-6 and USW H-7; other holes to be used as observation wells. |
| Water supply testing | J-12<br>J-13 | 8.3.1.16.2.1.1 | Assess feasibility and adequacy of wells J-12 and J-13 for use in construction and operation of Yucca Mountain repository. Located just outside conceptual boundary of controlled area. |
| Saturated zone recharge studies, testing | UE-25 FM#1<br>UE-25 FM#2<br>UE-25 FM#3 | 8.3.1.2.1.3.3 | Infiltration measurements as part of Fortymile Wash recharge study. Dry drilled to the water table. |
| Water table studies testing | USW WT-8<br>UE-25 WT#19<br>UE-25 WT#20<br>USW WT-23<br>USW WT-24 | 8.3.1.2.3.1.2 | Site potentiometric level study; water level monitoring, and water pumping/sampling. |
| | USW WT-21<br>USW WT-22 | 8.3.1.2.1.3.2 | Regional potentiometric level study; water level study; water level monitoring, and water pumping/sampling. WT-22 is located >5 km from conceptual perimeter drift boundary. |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 7 of 8)

| Activity category | SBIP[a] designation | SCP activity | Description | Remarks |
|---|---|---|---|---|
| Water table studies testing (continued) | USW WT-1<br>USW WT-2<br>UE-25 WT#2<br>UE-25 WT#4<br>UE-25 WT#6<br>USW WT-7<br>USW WT-10<br>USW WT-11<br>UE-25 WT#12<br>UE-25 WT#13<br>UE-25 WT#14<br>UE-25 WT#15<br>UE-25 WT#16<br>UE-25 WT#17 | 8.3.1.2.3.1.2<br>8.3.1.2.3.2.2 | Site potentiometric level study; water level monitoring, and water pumping/ sampling. | |
| | USW G-5<br>USW G-6<br>USW G-7 | 8.3.1.4.2.1.1<br>8.3.1.17.4.8.2<br>8.3.1.2.3.2.2 | Correlate lithologic changes with appropriate structural and hydrologic information; sample water from saturated zone; possibly perform hydrofract stress measurements. | |
| In situ stress studies | USW ISS-1 | 8.3.1.17.4.8.2 | Measure in situ stress. | Shallow hole >250 m. |
| Conceptual repository surface facilities site; borehole testing | RSF #1<br>RSF #2 | 8.3.1.14.2.1.3 | Geophysical measurements of dynamic soil properties to support engineering design/ environmental hazard assessment. | |

Table 8.4.2-9. Summary of planned subsurface drilling-related characterization activities (page 8 of 8)

Footnotes

[a]Surface-Based Investigations Plan (DOE, 1988d).

[b]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.

[c]Controlled area is the actual area chosen according to the 40 CFR 191.12(g) definition.

[d]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[e]Borehole designation is to be determined. This is a conceptual activity and plans are not presently included in the Surface-Based Investigations Plan.

Site vertical borehole studies (Activity 8.3.1.2.2.3.2)

The drilling program under this activity involves dry drilling and coring of 17 vertical boreholes, within and in the immediate vicinity of the conceptual perimeter drift boundary. At present, seven of these boreholes have been at least partially drilled. This includes a series of relatively shallow unsaturated zone boreholes designed to penetrate only to the top of the Topopah Spring welded unit, and several deeper boreholes that penetrate the repository horizon and most of the unsaturated portion of the Calico Hills nonwelded unit. The shallow boreholes were drilled dry using the ODEX 115 system with continuous wireline coring to depths up to 430 ft (F&S, 1987b). Plans call for deepening of UE-25 UZ#4, UE-25 UZ#5, USW UZ-7, USW UZ-8, and USW UZ-13 to the water table.

The balance of the unsaturated-zone program consists of 10 boreholes drilled to just above the water table. Two of these boreholes (USW UZ-1 and USW UZ-6) have already been drilled dry using a reverse vacuum rotary method (Whitfield, 1985). The depth of penetration attained with the reverse vacuum method exceeded that possible with the ODEX method used for shallow borehole drilling and coring in the unsaturated zone. A third borehole (USW UZ-6s) has also been drilled dry near USW UZ-6 to a depth of about 519 ft using the ODEX 165 system (nominal 8.5-in. borehole diameter; F&S, 1987b). Neither the reverse vacuum method nor the ODEX 165 method provided core samples. Accordingly, the particular drilling method that will be used for the planned UZ boreholes has not yet been determined.

At least two candidate drilling schemes have been considered for planned dry drilling to the water table, with continuous sampling suitable for hydrologic data needs: (1) dual-tube reverse circulation (DTRC) rotary or down-the-hole hammer technology, and (2) a telescoping ODEX concept similar to the shallow UZ program, with provision for stepdown tool sizes to attain required depth penetration. Feasibility testing of one or more alternative drilling methods will be conducted at the location of the planned UE-25 UZ#9 complex of boreholes, about 0.5 km southeast of the CPDB. The selection of the drilling method for the unsaturated-zone boreholes, the multipurpose boreholes, and the systematic drilling program will be based on this feasibility test.

The oil content of circulation air will be limited to the extent practicable by filtration, unless a down-the-hole motor or hammer is used (i.e., ODEX drilling), in which case oil will be required for tool lubrication in amounts consistent with standard drilling practices. If such drilling methods are used, bench-scale testing will be performed to evaluate the effects of oil on matrix hydrologic properties. Similarly, the drying effects of circulating air on matrix-property measurements and in situ hydrologic conditions are currently under investigation in the wet vs. dry prototype test in G-tunnel on the Nevada Test Site.

Each of the unsaturated-zone boreholes will be pneumatically tested using straddle packers (Activity 8.3.1.2.2.3.2). Where boreholes are closely spaced, crosshole testing will be performed. A gaseous tracer will be added to injected air. The specific intervals to be tested, test durations, and other parameters have not yet been determined. At the conclusion of pneumatic testing at each location or complex of boreholes, instrument packages

will be installed in each of the unsaturated-zone boreholes. These long-term installations will be used for monitoring, similar to the instrumentation of USW UZ-1 (Montazer et al., 1985).

After the conclusion of monitoring at some future time yet to be determined, water-injection testing is planned. The sampling apparatus and stemming configuration from monitoring will be used for injecting moderate quantities of water. These tests are tentative and have, therefore, not been included in the test interference discussion of Section 8.4.2.2.3. The potential test interference and site performance impacts of this type of water injection will be evaluated before its implementation, on the basis of information acquired from the preceding parts of the study.

The primary objective of the unsaturated-zone drilling program is to characterize natural conditions of moisture percolation and gaseous circulation. Models will be developed, verified and calibrated from the data collected. The rationales for siting the individual boreholes are based on the need to examine the effects of faulting, topographic relief, and surface drainage on hydrologic conditions at depth. The two clustered sets of boreholes (USW holes UZ-6, UZ-2, and UZ-3; and UE-25 holes UZ#9, UZ#9a, and UZ#9b) will support multihole pneumatic flow testing for vertical and lateral flow properties, in different surface hydrologic and structural settings. The USW UZ#9 complex will also support gas tracer diffusion studies. Boreholes USW UZ-11 and USW UZ-12 will be drilled on either side of the Solitario Canyon fault, and USW UZ-7 and USW UZ-8 will straddle the Ghost Dance fault, to investigate flux on either side of each fault. Boreholes UE-25 UZ#4 and UE-25 UZ#5 are located in the relatively deeply alluvial-filled Pagany Wash. USW UZ-14 will be near existing borehole USW UZ-1, for investigation of the apparent perching of drilling fluid from borehole USW G-1. USW UZ-13 will sample conditions south of the CPDB.

Multipurpose borehole activity (Activity 8.3.1.2.2.4.9)

The proposed multipurpose borehole (MPBH) activity would involve drilling a vertical borehole near the location of each shaft of the ESF to collect baseline data, which would allow the evaluation of interference of ESF shaft and drift construction with testing and the detection and characterization of possible perched water. Possible interference effects include (1) alteration of natural hydrochemistry from dilution of other interaction with artificially introduced fluid, (2) deposition of such fluid in fractures, and (3) deposition of such fluid in the rock matrix. The proposed MPBH activity would also detect and characterize possible perched water, characterize in situ hydrologic conditions, and obtain samples for analysis before constructing the shafts. If perched water is intersected by either shaft, various practical problems (e.g., the geometry of exposure and contamination from fluid use in shaft construction) could prevent adequate characterization of the aquifer. The proposed MPBH activity would be designed to minimize this potential problem by detecting and characterizing perched water before shaft construction. If results warrant, a third MPBH would be drilled intermediate between the two shafts.

Tracer analysis is a component of the strategy to ensure the representativeness of samples obtained from the ESF for matrix hydrologic properties,

hydrochemistry, and other investigations. The proposed MPBH activity would provide an important comparative basis for evaluating the quality of these samples.

Each of the proposed MPBH activity boreholes would be drilled to the maximum depth of the respective shaft. The specific location of each hole would be determined to meet the requirement for long-term surface access for monitoring, the requirement to locate the boreholes at least two drift diameters away from any underground openings, and the requirement to not penetrate the mechanical zone of influence expected to occur around each shaft. Dry drilling and coring are necessary. The drilling method for this application has not been selected; the selection would be based on feasibility testing conducted in conjunction with the unsaturated-zone drilling program. At the conclusion of drilling, a surface casing would be cemented in place, and geophysical logging and pneumatic packer testing will commence. Short-term logging and packer testing would be repeated throughout the process of ESF surface facilities construction, shaft construction, and testing in the shafts. Long-term monitoring would monitor the behavior of the rock mass between the MPBH and the shaft. The boreholes would be uncased throughout the monitoring period; the surface casing would be capped when testing is not in progress to inhibit moisture efflux. The option of instrumenting the boreholes would be maintained.

Systematic drilling program (Activity 8.3.1.4.3.1.1)

The systematic drilling program consists of drilling twelve boreholes within the CPDB or in its immediate vicinity, to collect samples and data on lithostratigraphy, basic physical properties, fracture characteristics, mineralogy, in situ moisture conditions, and other characteristics, as discussed in Section 8.4.2.1.4. This information will address various information needs, particularly for the model for unsaturated-zone flow and transport. The systematic drilling program is also an important source of samples for geomechanical, geochemical, and geophysical studies. Seven of these boreholes are distributed across the site area, and in conjunction with other planned drilling will provide areal coverage of the site with about 3,000-ft spacing between boreholes. The other five boreholes of the systematic drilling program are clustered immediately to the southeast of the CPDB to provide information on small-scale lateral variability of matrix hydrologic properties and other parameters. Each borehole will be drilled to approximately 200 ft below the water table. Nonwelded and partially welded intervals will be continuously cored, and welded intervals will be continuously cored if feasible; otherwise, they will be spot cored on a regular basis. The boreholes will be drilled dry to reduce disturbance to the hydrologic and hydrochemical properties of the samples acquired. The drilling method has not been determined, and the selection will be based on results from the feasibility testing described above.

The locations of the drillholes in the systematic drilling program will be determined using several criteria: (1) integration with the conceptual repository design; (2) areal coverage of the CPDB; (3) accommodation of basic geostatistical principles; and (4) integration with other boreholes, both existing and planned, that can provide additional supporting data for modeling spatial variability of rock characteristics. The planned systematic drilling is based on statistical principles, and will thereby provide a basis

for evaluating representativeness of samples and data (Sections 8.4.2.1.5.3 and 8.3.1.4.3.1.1).

Solitario canyon horizontal borehole study (Activity 8.3.1.2.2.3.3). This borehole will be drilled laterally into the Topopah Spring welded unit, at the Solitario Canyon scarp where the upper part of this unit is exposed at the site (Activity 8.3.1.2.2.3.3). The location of this borehole has been tentatively identified as about 2,000 ft north-northwest of the CPDB. The borehole will be drilled dry to provide representative information on in situ moisture conditions. The length of the borehole will be sufficient to penetrate the zone of fracturing or alteration associated with the fault; this could require a borehole up to 1,000 ft long. Important uncertainties pertaining to this planned borehole are (1) the engineering feasibility of drilling, testing, and stemming a long horizontal hole through relatively highly fractured conditions, and (2) the method of plugging a horizontal borehole, should this be required. These questions will be evaluated before drilling of the borehole.

Geologic coreholes. A series of three coreholes is planned for Activity 8.3.1.4.2.1.1, to investigate subsurface structure and stratigraphy north and south of the site area. Each corehole will be drilled using standard wire-line coring methods to 5,000-ft depth. The drilling method for these coreholes will be similar to that used for existing boreholes USW G-1, USW G-2, and USW G-3 (F&S, 1987c), in which the principal circulation medium was water with additives (bentonite mud and other materials were occasionally used for circulation control). As indicated in Section 8.4.2.2.1, the proposed geologic coreholes USW G-5, USW G-6, and UE-25 G#7 are located outside the conceptual boundary of the controlled area, and outside the possible expansion areas proposed in the Yucca Mountain environmental assessment (Figure 3-8; DOE, 1986b). New roads are required for access to the proposed locations; the existing road network will be used to the extent practicable, and new road construction will be away from the CPDB and mostly outside the controlled area.

The planned geologic coreholes will allow interpolation of lithologic characteristics between the repository area, where more densely spaced boreholes may be drilled (e.g., systematic drilling program), and the controlled area boundary. The objectives of these coreholes will be to better explain inferred geologic and geophysical anomalies and to characterize large-scale lithologic variability in the Paintbrush Tuff, tuffaceous beds of Calico Hills, and Crater Flat Tuff.

Corehole USW G-5 will be sited along the northeastern flank of Yucca Mountain to determine if abrupt changes in lithologies of underlying units or changes in structural style within Yucca Wash are factors that influence the steeper gradient in the potentiometric surface north of drillhole USW G-1. The planned location of USW G-6 is on the northwest flank of Yucca Mountain, in the vicinity of Windy Wash and is expected to provide representative stratigraphic data for this area and allow correlation of thickness of key stratigraphic units across the site area. USW G-7 will be sited about 5 km southeast of Busted Butte in the southern part of Yucca Mountain, within the area where the Paintbrush Tuff thins and appears to onlap an inferred high in the pre-eruptive topography. This corehole will be used to determine the nature of this feature and its effect on ground-water travel times and

potential flow paths in southern Yucca Mountain for saturated-zone flow modeling.

Saturated-zone exploration, sampling, and testing

Eight boreholes are planned specifically for exploration and sampling of the saturated-zone in the vicinity of the site, in addition to the 16 such boreholes that already exist (Activity 8.3.1.2.3.1.2). Also, a new borehole (USW H-7) is planned just within the CPDB to address multiple objectives. A program of sampling will be conducted in the water-table boreholes (existing and proposed), and a series of pumping tests will be performed in USW H-7 and in other boreholes in the site vicinity (USW H-6 and USW WT-8).

Water-table boreholes

The locations of the eight water-table boreholes planned for Activity 8.3.1.2.3.1.2 are presented in Section 8.4.2.2.1. Two of these boreholes, USW WT-21 and USW WT-22, will be drilled in connection with the regional potentiometric-level evaluation discussed below. The other six (USW WT-8, USW WT-9, USW WT-23, USW WT-24, UE-25 WT#19, and UE-25 WT#20) will be added to the site potentiometric-level network. Presently, 25 geologic, hydrologic, and water-table drillholes are part of the monitoring network near the site. The objectives of this drilling program are to provide data needed to refine understanding of the configuration of the potentiometric surface, analyze the character and magnitude of water-level fluctuations to determine their causes, and measure water-level variations with time. In addition, the boreholes will be used to sample the upper part of the saturated-zone and to sample gases immediately above the water table.

Water-table drillholes USW WT-8 and USW WT-9 will be located near the Solitario Canyon fault to characterize the hydrologic effects of that structural feature (Activity 8.3.1.2.3.1.1). Drillholes USW WT-23 and USW WT-24 will be sited to the north near Drill Hole Wash to obtain needed data on the steep gradient in this area. Drillhole WT-23 will be sited in Drill Hole Wash, northwest of drillhole USW UZ-1, and borehole WT-24 will be sited between drillholes USW G-2 and UE-25 WT#18. Drillholes UE-25 WT#19 and UE-25 WT#20 will augment the potentiometric-level monitoring network south and east of the repository site. Borehole WT#19 will be sited 3 km east of water well J-13 and borehole WT#20 will be sited 5 km southwest of well J-13.

The Solitario Canyon boreholes USW WT-8 and USW WT-9 will be drilled dry, using a method similar to that used for the systematic drilling program and based on feasibility testing performed for the unsaturated-zone drilling program described earlier. The other water-table (WT) boreholes are farther from the CPDB and will be drilled using a simple rotary method with conventional circulation and air foam. The depth of each borehole will be 100 to 200 ft below the static water level (1,300 to 2,000 ft below ground level). The boreholes will be uncased except for a cemented surface casing with an operable closure, and they will have a string of small-diameter tubing hung from the surface to the water table for water-level monitoring. Fluid use was not monitored during the construction of the 16 existing WT boreholes; however, borehole history information (F&S, 1986) and supporting drillers' logs may be used to infer that about 100,000 gallons of water-soap mixture was typically lost to the unsaturated zone in each borehole. This

value was estimated from the recorded number of barrels of detergent used, assuming that the water-to-soap ratio was 150 to 1, and 50 percent of the injected fluid was lost to the unsaturated zone. Similar fluid loss is expected to occur in the proposed WT boreholes, except in those that will be drilled dry.

Water-table borehole sampling

Since most of the water table boreholes will be drilled with air foam circulation, the hydrochemistry of the intercepted ground water probably will be disturbed during drilling. Special methods will therefore be used to obtain representative water samples (Activity 8.3.1.2.3.2.2). Present plans call for removing the tubing string from each water table borehole, placing a small pump on a tubing string of adequate cleanliness, and pumping for an indeterminate time period. The original tubing string will then be rehung and water-level monitoring resumed. The pump output will be continuous at approximately 15 gpm and will be maintained for up to several weeks, or until the water composition stabilizes and there are other indications that the composition represents uncontaminated ground water. The effluent water will be removed from the vicinity of the site in tank trucks, except for locations where natural drainage tends to divert discharge from the site and from unsaturated-zone hydrologic studies, including USW WT-1, USW WT-7, USW WT-10, USW WT-22, UE-25 WT#12, UE-25 WT#17, UE-25 WT#19, and UE-25 WT#20. Water that is discharged to natural drainages will be tagged with a chemical tracer.

Saturated-zone hydrologic borehole USW H-7

A 3,000-ft vertical borehole will be drilled in Solitario Canyon to obtain potentiometric-level information and to test the hydrologic properties of the Solitario Canyon fault zone in conjunction with existing borehole USW H-6 (Activity 8.3.1.2.3.1.1). This borehole will be drilled about 3,000 ft east of USW H-6, using dry drilling methods at least through the unsaturated-zone. For flow testing, a pump with lift capacity of approximately 500 gpm will be installed successively in USW H-7 and existing USW H-6. Each borehole will thus serve as a pumping and observation well in a multi-well testing scheme. A temporary pipeline will be constructed to conduct discharge water away from the site and away from sensitive hydrologic studies. The tentative route of the pipeline will be down Solitario Canyon to Crater Flat. Water discharged from the pipeline will have been tagged with a chemical tracer.

Other saturated zone testing

A series of single-well and multiple-well pumping tests will be conducted in the existing C-hole complex (UE-25c#1, UE-25c#2, and UE-25c#3). This is an existing set of 3,000-ft boreholes drilled using the rotary air foam method, in a location more than 5,000 ft southeast of the CPDB. This location was selected as representative of saturated-zone pathways from the repository to the accessible environment.

About 20 pumping tests are planned, using various pumping wells, pumping intervals, observation intervals, and tracer injection schemes (Activities 8.3.1.2.3.1.5 and 8.3.1.2.3.1.7). The single-well pumping tests will involve

installing a submersible pump in an isolated interval, pumping from that interval at 50 to 200 gpm for about 3 days, and recording the pressure history in selected intervals during and after pumping. A 30-day pumping test is also planned, which will involve pumping one of the C-holes at 100 to 400 gpm and monitoring the pressure decline in the other nearby boreholes. Water produced during these tests will be discharged through a short pipeline into the natural drainage system that flows northward for about 2 km through Midway Valley, and around the northern end of Fran Ridge into Fortymile Wash. No planned or existing hydrologic studies are located in this portion of Midway Valley, and the resulting infiltration is expected to occur west of Fran Ridge and not affect the planned recharge studies in Fortymile Wash.

Multiple-well recirculation tests are also planned at the C-hole complex. These tests will involve pumping from a selected interval in one well and injecting into another interval in a different well. Circulation will be maintained at approximately 100 to 300 gpm for several days until quasisteady state conditions are established. Conservative chemical tracers will be mixed with the injected water.

In addition to the pumping tests described above, about three drift-pumpback tests are planned in the C-hole complex. A conservative or reactive tracer solution will be placed in a test interval and allowed to drift into the formation, then be pumped out. The pumping rate for these tests will be approximately 50 to 150 gallons per minute. Pumping will continue for several days, or until the tracer material is substantially recovered. One objective of the overall tracer testing program in the C-hole complex is to determine if the variation of saturated-zone hydrologic properties across the site can be investigated through the use of single-well tests in existing boreholes. Depending on the outcome, additional single-well tracer testing may be performed in water table boreholes across the site area. If the results of single-well testing lead to the conclusion that the objectives cannot be met by such a test, a second multi-well complex for saturated-zone testing may be constructed (southern tracer complex), possibly near Busted Butte or immediately westward.

Regional potentiometric-level drillholes

A general reconnaissance will be conducted to locate previously unknown or unobserved wells, springs, and mine shafts that are not associated with the Yucca Mountain Project and that may yield information about regional ground-water levels. Also, a commercial mining company in the Amargosa Desert has allowed the Yucca Mountain Project to install piezometers in their boreholes for water-level data collection. In addition to these non-Project activities, two Project drillholes, USW WT-21 and USW WT-22, will be drilled in Crater Flat. These boreholes will be drilled to depths necessary to penetrate the water table. The objective of the regional potentiometric-level activities is to obtain data on potentiometric-levels within the regional flow system in order to reliably estimate ground-water flow directions and hydraulic gradients.

Other boreholes

In addition to those just described, several other boreholes are planned, as indicated in Table 8.4.2-9. These holes are generally remote from the site but are described here for completeness. A series of five or more shallow holes (approximately 200 ft deep) will be drilled in the vicinity of Exile Hill, just east of the site, to explore subsurface expression of the Trench 14 vein deposits. Two shallow exploratory holes (RF-series boreholes) are planned for Midway Valley east of Exile Hill for further testing of the proposed location for the repository surface facilities. Three or more boreholes to the water table and several shallow neutron-access holes are planned for recharge studies in Fortymile Wash, a few miles east of the site (FM-series boreholes). A series of four holes to about 1,000 ft depth are planned in Crater Flat to investigate the buried volcanic deposits that are the cause of aeromagnetic anomalies (V-series boreholes). One or two additional holes in the Yucca Mountain region are planned to measure in situ stress by hydraulic fracturing; the number and locations of these boreholes is yet to be determined.

8.4.2.2.2.3 Basis for surface-based testing construction controls

Water use during site characterization

An estimated 4.5 million gallons of water will be used for surface-based drilling (based on current SCP planning) during site characterization. An additional estimated 1.1 million gallons will be used during surface-based testing, and an estimated 35 million gallons (for five years of surface-based site characterization activity) will be used for maintenance, including dust control for access roads. An estimated 33.2 million gallons of water will be used during construction and testing associated with the ESF (West, 1988). Of the total water-use requirement for the ESF, approximately 3.2 million gallons will be used underground for shaft sinking and testing, station construction, underground construction, and test construction and support. The remaining estimated 30 million gallons will be used at the surface during site preparation, construction and maintenance (i.e., dust control) activities.

The DOE has applied to the State of Nevada for a water appropriations permit for well J-13 water (Application for Permit No. 52338). The appropriation applied for was 131 million gallons or 402 acre feet to be used for site characterization at Yucca Mountain. The difference between the water use estimates described previously and the appropriation applied for is the result of revisions of test plans and construction controls, specifically, (1) dry drilling is now specified for the systematic drilling program, and for other drilling within the CPDB and immediate vicinity; (2) the systematic drilling program and in situ stress measurement activities have been revised; (3) the amended water application considered more than 6 years of use versus 5 years as described previously in this section; (4) water use for surface dust control at the ESF has been overestimated, and (5) a 10 percent contingency has been applied to water needs for ESF construction, in the amended application.

The use of larger figures in the water application is necessary because of uncertainties regarding estimates of water use. For example, the largest expected use of water is for surface dust control on roads. Most of the road mileage associated with site characterization is situated outside the CPDB, and effective dust control on such roads may require additional water in excess of the estimates. Water needs for dust control are particularly difficult to estimate and will vary with environmental and operating conditions. Despite the intention of the Project to minimize water use during site characterization, it is important to have sufficient appropriation to meet unanticipated needs, especially those related to safety, such as dust and fire control.

Water-use estimates for planned surface-based testing are given for drilling, testing, and maintenance (primarily for dust suppression on roads as described earlier) in Tables 8.4.2-10 and 11. These estimates should be considered maximum amounts that will be used under anticipated conditions. None of the water estimated for use in surface-based drilling will be used for boreholes located within the CPDB, given planned construction controls. Approximately 400,000 gallons of water will be used in surface-based tests that may be located within the CPDB. Well J-13 is the planned source of all the water used for site characterization.

Dry drilling

A key aspect of construction control for surface-based testing, including infiltration testing, unsaturated-zone hydrology testing, and the systematic drilling program, is the selection of dry drilling or coring methods. The determination to use air circulation in drilling-related operations associated with these activities is based on three criteria: (1) core or cuttings samples should be reasonably free of hydrologic invasion or hydrochemical contamination by drilling fluid; (2) for studies where monitoring of in situ hydrologic conditions is planned, the environment in the immediate vicinity of monitoring boreholes should be reasonably free of artificially introduced moisture, or other perturbation caused by drilling (e.g., contamination); and (3) for activities located within or close to the CPDB, drilling operations should not result in the loss of fluid into the unsaturated-zone, which could have a deleterious effect on the representativeness of site characterization data, or on the waste-isolation performance of the site.

Unsaturated-zone hydrologic data and sample requirements

Core samples from the unsaturated zone are needed for such tests as measurement of unsaturated matrix conductivity and extraction of pore fluid. Various dry sampling methods were used in the neutron-access borehole drilling program with different results, depending on the materials being sampled; these methods included cuttings, drive sampling, and air rotary coring (Hammermeister et al., 1985). Although of limited applicability, these results show that a dry sampling method in addition to cuttings is needed, that drive sampling produces bias in sample water-content data due to mechanical effects but is adequate for sampling unconsolidated materials, and that air rotary coring probably is adequate for sampling nonwelded and welded material.

Table 8.4.2-10. Water-use estimates (in gallons) for planned surface-based activities--drilling and testing[a] (page 1 of 3)

| Activity category | Borehole designation | Within conceptual perimeter drift boundary[b] | Within controlled area boundary[c] | Outside the controlled area boundary |
|---|---|---|---|---|
| | | DRILLING | | |
| Shallow boreholes (<100 ft deep) | | 0 | 0 | 0 |
| Site vertical boreholes | USW UZ-2 | 0 | | |
| | USW UZ-3 | 0 | | |
| | UE-25 UZ#4[d] | | 0 | |
| | UE-25 UZ#5[d] | | 0 | |
| | USW UZ-7[d] | 0 | | |
| | USW UZ-8[d] | 0 | | |
| | UE-25 UZ#9 | | 0 | |
| | UE-25 UZ#9a | | 0 | |
| | UE-25 UZ#9b | | 0 | |
| | USW UZ-10 | | 0 | |
| | USW UZ-11 | | 0 | |
| | USW UZ-12 | | 0 | |
| | USW UZ-13[d] | | 0 | |
| | USW UZ-14 | | 0 | |
| Vertical seismic profile support/ unsaturated-zone prototype | UE-25 VSP#1 | | 0 | |
| Solitario Canyon horizontal hole | To be determined | | 0 | |
| Multipurpose boreholes[e] | USW MP-1 | 0 | | |
| | USW MP-2 | 0 | | |
| Saturated-zone borehole | USW H-7 (below water table only) | | 151,200 | |
| Water-table boreholes | USW WT-8 | | 0 | |
| | USW WT-9 | | 0 | |
| | UE-25 WT#19 | | | 100,800 |
| | UE-25 WT#20 | | | 100,800 |
| | USW WT-21 | | 100,800 | |
| | USW WT-22 | | | 100,800 |
| | USW WT-23 | | 100,800 | |
| | USW WT-24 | | 100,800 | |

Table 8.4.2-10. Water-use estimates (in gallons) for planned surface-based activities--drilling and testing[a] (page 2 of 3)

| Activity category | Borehole designation | Within conceptual perimeter drift boundary[b] | Within controlled area boundary[c] | Outside the controlled area boundary |
|---|---|---|---|---|
| | DRILLING (continued) | | | |
| Geologic coreholes | USW G-5 | | | 630,000 |
| | USW G-6 | | | 630,000 |
| | USW G-7 | | | 630,000 |
| Volcanic boreholes | USW V-1, V-2, V-3 and V-4 | | | 268,000 |
| Calcite silica vein deposit coreholes | UE-25 PH#1 (5 slant holes) | | 84,000 | |
| | UE-25 PH#2 (if needed) | | 16,800 | |
| Systematic Drilling Program (12 holes total, 5 within the conceptual perimeter drift boundary and 7 within the controlled area boundary) | | 0 | 0 | |
| Southern tracer complex (if needed) | STC-1 | | 302,400 | |
| | STC-2 | | 302,400 | |
| | STC-3 | | 302,400 | |
| | STC-4 | | 302,400 | |
| Conceptual repository surface facilities coreholes | UE-25 RF#12 | | 100,800 | |
| | UE-25 RF#13 | | 100,800 | |
| In situ stress borehole | UE-25 ISS#1 | | | 67,200 |
| Drilling totals | | 0 | 1,965,600 | 2,528,400 |

Table 8.4.2-10. Water-use estimates (in gallons) for planned surface-based activities--drilling and testing[a] (page 3 of 3)

| Activity category | Borehole designation | Within conceptual perimeter drift boundary[b] | Within controlled area boundary[c] | Outside the controlled area boundary |
|---|---|---|---|---|
| | | PLANNED SURFACE-BASED TESTING | | |
| Artificial infiltration | Small plot rainfall simulation (23 sites) | 960 | 1,800 | |
| | Large plot rainfall simulation (14 sites) | 9,000 | 33,000 | |
| | Ponding studies | 340,000 | 660,000 | |
| In situ stress tests | UE-25 ISS#1 | | | 5,000 |
| | (at an existing hole near the site) | | 5,000 | |
| Tracer tests | UE-25 C-hole complex (up to 10 tests) | | 10,000 | |
| Testing Totals | | 349,960 | 709,800 | 5,000 |

[a]Water use figures are given only for areas where drilling or testing will occur.

[b]The conceptual perimeter drift boundary is the projection to the surface of the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" (Rautman et al., 1987).

[c]Controlled area is the actual area chosen according to the 10 CFR 60.2 definition.

[d]These are existing shallow unsaturated-zone boreholes (<500 ft in depth). They will be reentered and drilled to depths necessary to penetrate the saturated zone.

[e]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.

Table 8.4.2-11. Water-use estimates for planned surface-based pumping tests[a]

| Activity category | Borehole designation | Approximate discharge rates (gpm) | Test duration (days) | Approximate gallons withdrawn |
|---|---|---|---|---|
| Solitario Canyon fault pump test | USW H-7 | 350-500 | 30 | 21,600,000 |
| | USW H-6 | 350-500 | 30 | |
| Drawdown pumping tests | UE-25C-hole complex | 50-400 | 3-5 & one 30-day test | 34,560,000 |
| | J-13 (primary water supply well) | 50-400 | 7 | 4,000,000 |
| Drift-pumpback tracer tests | UE-25C-hole complex | 50-150 | 3 | 1,944,000 |
| Two-well convergent tracer tests | UE-25C-hole complex | 100-300 | 24 | 24,192,000 |
| Two-well recirculating tracer tests | UE-25C-hole complex | (minimal discharge for sampling only) | | |
| Drawdown pumping tests before the drift-pumpback tests[b] | UE-25a #1 | 50-200 | 3-5 | 1,440,000 |
| | UE-25b #1 | 50-200 | 3-5 | 1,440,000 |
| | USW G-4 | 50-200 | 3-5 | 1,440,000 |
| | USW H-1 | 50-200 | 3-5 | 1,440,000 |
| | USW H-3 | 50-200 | 3-5 | 1,440,000 |
| | USW H-4 | 50-200 | 3-5 | 1,440,000 |
| | USW H-6 | 50-200 | 3-5 | 1,440,000 |
| Drift-pumpback tracer tests throughout the site[b] | Same as above | 50-150 | 3 | 4,536,000 |
| Drawdown pumping tests for recirculating tracer tests[b] | 4 southern tracer-complex boreholes | 100-300 | 28 | 24,192,000 |

[a]Discharge amounts were estimated using the maximum pumping rate and the maximum number of days tentatively planned for each test.

[b]Either the drift-pumpback tests or the recirculating pumping tests will be conducted. The type of additional tracer tests depends on results of the previous tests conducted at the C-hole complex.

In principle, samples should be drilled dry to preserve in situ conditions, but the value of dry drilling has not actually been demonstrated. This will be addressed in a prototype test program for evaluating the effects of wet and dry drilling fluids on the in situ hydrologic properties of tuffaceous rocks. This test will involve coring, testing, and monitoring of closely spaced parallel boreholes in the G-tunnel Rock Mechanics Facility located at the Nevada Test Site. Both dry and conventionally (water) drilled coreholes will be investigated in both welded and nonwelded units. This program will provide hydrologic measurements under closely controlled conditions, for use in preliminary application of unsaturated flow models to provide a theoretical basis for understanding the hydrologic effects of different drilling and excavation methods.

Formation invasion by fluid

Controlled field experiments have shown that water injected into the unsaturated zone during conventional drilling or flow testing under saturated conditions may mobilize over unanticipated distances by apparent channel flow, and that once in the formation this water can change the measured pneumatic conductivity. Because most of the studies in the unsaturated-zone hydrology program, including those in the ESF, will measure the rock-mass hydraulic conductivity, the choice of drilling method could significantly impact the results from unsaturated-zone hydrologic testing in the ESF and from surface-based programs. Dry drilling and coring methods provide the highest assurance that such impacts are minimized. Field testing of the effects of different drilling methods and drillhole inundation on measurable in situ hydrologic characteristics of the unsaturated zone will be incorporated in the wet versus dry prototype test in G-tunnel.

Slightly more than 500,000 gallons of water-based drilling fluid were lost to the unsaturated zone during drilling of USW G-1, of which traces were detected about two years later during drilling of borehole USW UZ-1, about 1,025 ft away. A significant effort (i.e., borehole USW UZ-14, Activity 8.3.1.2.2.3.2) is planned to resolve the specific origin of this fluid and the structural conditions that contributed to its movement.

All the existing boreholes within the CPDB or immediate vicinity were drilled dry (USW UZ-6, USW UZ-6S, USW UZ-7, and USW UZ-8) or with air foam (USW G-4, USW H-4, USW H-5, and USW WT-2). The use of air foam has resulted in the loss of approximately 100,000 to 200,000 gallons per hole. Total recorded fluid use for these boreholes was about 2 million gallons. The amount actually lost to the unsaturated zone was approximately 850,000 gallons; the balance was recovered and dispersed or evaporated in pits at the surface. Borehole television logs made during drilling operations show water inflow from the fractures and lithophysae intersected by the borehole. While reduction in overall fluid loss was gained by the use of air foam instead of water or mud (with the application of lost-circulation materials), losses in the unsaturated-zone were comparable in the boreholes for which data are available. Based on prior drilling history at Yucca Mountain, dry drilling is the only demonstrated means of controlling formation invasion by fluid.

The need to reduce uncertainty concerning the hydrologic conditions and processes operating at the site suggests that further fluid losses should be avoided until uncertainty is reduced. Fluid already lost during pre-site characterization activities can be considered to have altered the state of moisture of the unsaturated zone, for which characterization is planned. However, if construction controls were to permit significant additional losses to the subsurface during site characterization, characterization data might not be representative of altered conditions. Dry drilling methods are therefore specified for planned drilling in the unsaturated-zone within the CPDB and immediate vicinity.

Most of the fluid that has been lost to the formation contains a conservative tracer, primarily lithium chloride, but lithium bromide has also been used. These salts were mixed with drilling water to produce a solution of approximately 20 ppm. The majority of boreholes drilled at or near Yucca Mountain (including all boreholes within the CPDB or in the immediate vicinity) used lithium chloride as a tracer. Several of the water-table drillholes used lithium bromide and a few boreholes drilled early in the site-selection process and located away from the CPDB (e.g., USW G-1) were drilled without the use of a tracer.

### 8.4.2.2.3 Surface-based test interference

Interference with surface-based testing is limited, principally because these activities are widely separated. Many surface-based testing activities such as mapping, trenching, and geophysical surveys are concerned with durable characteristics of the site that generally are unaffected by interference. Hydrologic monitoring activities in the unsaturated zone, such as the site vertical boreholes study (Activity 8.3.1.2.2.3.2) or the gas-phase circulation study (Activity 8.3.1.2.2.6.1), may detect the influence of hydrologic stress tests such as pneumatic packer testing from neighboring boreholes, but this would be unexpected because the various test locations are far apart. Similarly, potentiometric-level interference caused by pumping tests in the saturated zone is possible and will be investigated. The events that could lead to this type of interference in the unsaturated or the saturated zone are under experimental control and can be knowingly evaluated if interference effects are suspected. The types of activities that have the most potential to produce interference effects are, therefore, (1) artificial introduction of water or gas wherever planned tests are located close together, thereby facilitating possible communication, and (2) disturbance to the structural characteristics of the site such that natural hydrologic processes are disturbed, producing interference with the measurements of those processes.

#### Possible interference from water use

The planned use of water in testing could potentially produce test-to-test interference if different activities are located close enough together, which is most likely in the immediate site area. The only significant testing-related use of water planned within the CPDB or the immediate vicinity is for the artificial infiltration tests, for which a total of up to 400,000 gallons of tagged water will be used within the CPDB. These tests

are planned in conjunction with the natural infiltration monitoring program and are widely separated from infiltration monitoring installations that could be adversely impacted. The other possibility is that water used in artificial infiltration testing could percolate deep into the unsaturated zone, thereby affecting measurements of the natural moisture state there, specifically in the site vertical boreholes study (Activity 8.3.1.2.2.3.2). Significant vertical and lateral movement of introduced water would be required, because the potentially interfering activities are widely separated. The evaluation reported in Section 8.4.3.2 indicates that moisture pulses from such sources may travel slowly. Furthermore, the chemically tagged water used in artificial infiltration testing could be identified during drilling of any borehole where such water is intercepted in sufficient quantity to significantly interfere with characterization of in situ matrix moisture conditions. This type of tracer detection strategy is relied upon in the multipurpose borehole activity (Activity 8.3.1.2.2.4.9) and the radial boreholes test in the ESF (Activity 8.3.1.2.2.4.4). In summary, the use of tagged water for artificial infiltration studies appears unlikely to interfere with planned natural infiltration monitoring or testing and monitoring in the deep unsaturated zone. However, the available information is inconclusive, so the potential for interference will be reevaluated as new information on lateral fluid mobility becomes available.

The other significant planned use of water within the CPDB or immediate vicinity is for dust suppression on roads. As discussed in Section 8.4.2.2.2, the dust control methods used previously at the site call for application of 1 to 2 mm of chemically tagged water, typically twice per day, under meteorologic conditions conducive to evaporation. This amount of water is not sufficient to produce significant runoff. Successive applications of water, however, could possibly produce saturation buildup in the road bed and underlying strata, which could conceivably interfere with natural infiltration monitoring, or with testing and monitoring in the deep unsaturated zone. Because road and pad surfaces are highly compacted and because of relatively large evaporative losses, dust suppression is unlikely to cause test interference. Natural infiltration study locations for monitoring undisturbed conditions are separated from roads and drill pads. For studies in the deep unsaturated zone, test interference depends on the mobility of moisture through the overlying drill pad and near-surface rock or alluvial material. This flow probably is restricted to the matrix of these materials and is, therefore, unlikely to penetrate to monitoring locations in the deep unsaturated zone in the time frame of site characterization. Further analysis of test interference, including the effects of watering for dust suppression, will be part of the study plans for the activities that may be affected.

Possible interference from disturbance to hydrologic processes

Construction of roads and drill pads alters the surface infiltration, runoff, and evapotranspiration characteristics of the site. For existing and planned roads at Yucca Mountain, this effect is associated primarily with devegetation and compaction of natural materials used for the road bed. Runoff from roads and pads is significantly increased for precipitation events that range from light events that cause runoff only from sloping road surfaces to heavy events that cause runoff from undisturbed surfaces. This type of runoff generally flows onto and infiltrates alluvium-filled, shallow

gradient areas at lower elevations. Increased runoff associated with surface disturbance probably tends to increase the saturation of near-surface materials in these infiltration areas. As this occurs, the capacity for infiltration into those materials decreases, thus extending the distance traveled by runoff. This effect is unlikely to interfere with infiltration measurements in upland areas, but may affect measurements in the canyons and washes of Yucca Mountain. Because of the distribution of natural-infiltration monitoring installations, some will probably register increased infiltration and the remainder will be unaffected. The impact of using affected information in site performance assessment is not currently understood, but the hydrologic characteristics of the areas disturbed by roads and pads are likely to return to pre-disturbance conditions relatively quickly, as a result of natural processes and eventual reclamation activities. This is a complex issue for which current understanding of site conditions and processes does not permit immediate resolution. Controls will be applied in the construction and maintenance of the features involving significant disturbance as discussed in Section 8.4.2.2.2, to reduce the magnitude of the interference effect to the extent practicable during site characterization. Knowledge that the effect probably exists will be applied throughout site characterization in the interpretation of infiltration data.

The other type of potential hydrologic interference involves the effect of borehole penetrations through the unsaturated zone on the natural movement of gas and vapor. Air has been observed to flow into and out of deep, open boreholes on the crest of Yucca Mountain (e.g., USW UZ-6), various neutron-access holes, and several of the WT-series boreholes. This flow is driven by seasonal and diurnal fluctuations in air density and local barometric pressure, and probably occurred in some form before construction of the boreholes. The flow generally involves inhalation of dry air and exhalation of moist air. All the existing boreholes at the site have surface casing and have been shut in except for intermittent observation periods. The significance of these observations to this discussion is that in situ hydrologic conditions will support appreciable flow (e.g., 10 ft/s in a 20-in. diameter hole) in response to potential gradients produced by atmospheric effects. No information is yet available on internal gas or vapor flow in shut-in boreholes.

Currently, five penetrations through the unsaturated zone exist within the CPDB at Yucca Mountain; of these, one is uncased and the remainder have tubing or casing installed throughout the unsaturated zone without cement (other than what was used to "tack" the lower end). A comparable number of existing holes stand uncased or uncemented through the unsaturated zone, in the immediate vicinity of the site. The casing is not fully cemented in boreholes in the vicinity of Yucca Mountain so that it can be readily removed for borehole sealing. Planned drilling for site characterization will produce at least 10 additional penetrations through the entire unsaturated-zone section within the CPDB, of which only three will be completed in such a way as to occlude flow in the open bore or the casing annulus. About 20 similar penetrations are planned for the surrounding vicinity (the exact number depends on the area considered). The same controls on casing cementation will apply to the planned program. The result will be boreholes spaced approximately 3,000 ft apart over the site area, and clusters of more closely spaced holes at the ESF location, near the USW UZ-6 location, and southeast of the CPDB near planned borehole USW UZ-9. The interference concern is that

once the site vertical boreholes (Activity 8.3.1.2.2.3.2) are instrumented and stemmed for long-term monitoring, internal circulation in the unsaturated-zone penetrations will affect the data collected.

Planned investigations are expected to provide the information needed to evaluate the extent of interference. Several studies are planned to evaluate the effects of air circulation through Yucca Mountain, and in open boreholes, to characterize test interference and the effect on repository performance, if any. One of the objectives for Study 8.3.1.2.2.6 (characterization of gaseous-phase movement in the unsaturated zone) is to describe the pre-waste-emplacement gas-flow field and identify the structural controls on fluid flow. Activity 8.3.1.2.2.6.1 plans to reconstruct the history of artificial effects on air circulation in the repository block and to relate flow rates to barometric pressure and air temperature changes. Flow-rate measurements will be made with a hot-wire anemometer under both open-hole and shut-in conditions. This information will be used with numerical simulation techniques to determine the volume of rock affected and the time required for the rock mass to return to pre-disturbance conditions. Gas flux and gaseous transport will also be investigated in Study 8.3.1.2.2.7 (hydrochemical characterization of the unsaturated zone).

### 8.4.2.3 Subsurface-based activities

The subsurface-based activities that are part of the site characterization program at Yucca Mountain consist of both the testing to be performed in the exploratory shaft facility and the associated construction and operations activities necessary to support the testing. This section briefly describes the planned testing, the supporting facility design, operations, and construction activities, as well as evaluates the layout for the operations that assess potential interference between activities.

The exploratory shaft facility (ESF) is illustrated conceptually in Figure 8.4.2-3. The ESF consists of surface facilities and underground excavations. The surface facilities include such items as headframes, a hoist house, shops, a warehouse, offices and laboratories, an electrical substation, integrated data acquisition facility, explosive magazines, waste-water treatment systems, and a muck-storage area. The underground excavations consists of two 12 ft finished diameter shafts, an upper demonstration breakout room (UDBR) off of ES-1, and drifts and alcoves on the main test level. The UDBR is about 600 ft deep and is in the TSw1 (moderately lithophysal) portion of the Topopah Spring tuff. The main test level is located at the planned repository horizon. The main test level consists of all the excavations made in the repository horizon from the two shafts. These excavations include (1) about 5,600 ft of long lateral exploratory drifts (i.e., those going to Drill Hole Wash, the Ghost Dance fault, and to the imbricate fault zone) and (2) about 4,000 ft of drifts within the dedicated test area (Figure 8.4.2-4). The dedicated test area was defined to facilitate integration of the ESF and the repository design and, specifically, to provide an area for use in both site characterization and performance confirmation testing. Within the dedicated test area there are service drifts and experiment drifts. Service drifts are designed to provide access to and support (ventilation, utilities, etc.) for the experiment drifts.

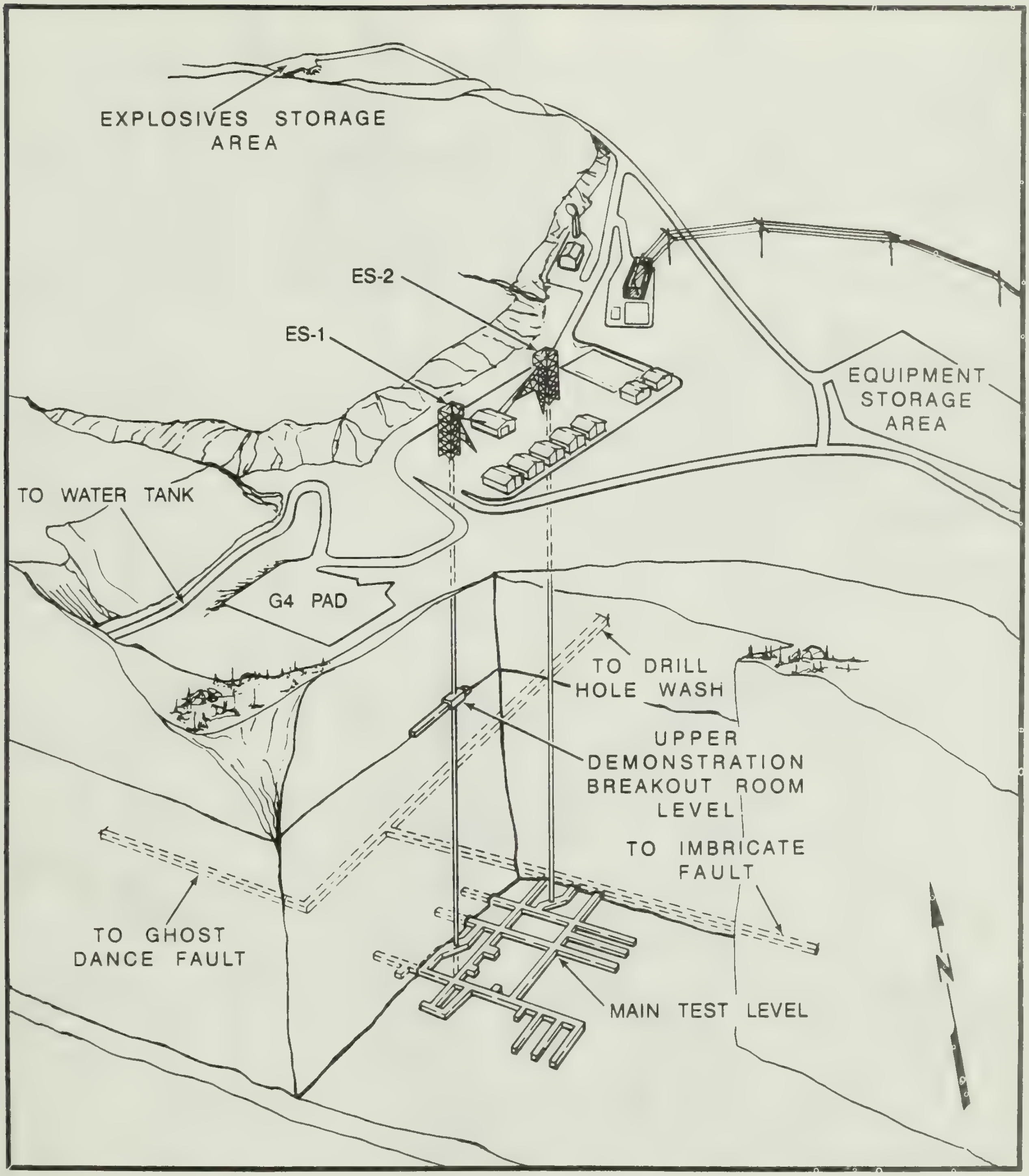



**Figure 8.4.2-3.** Conceptual illustration of the exploratory shaft facility

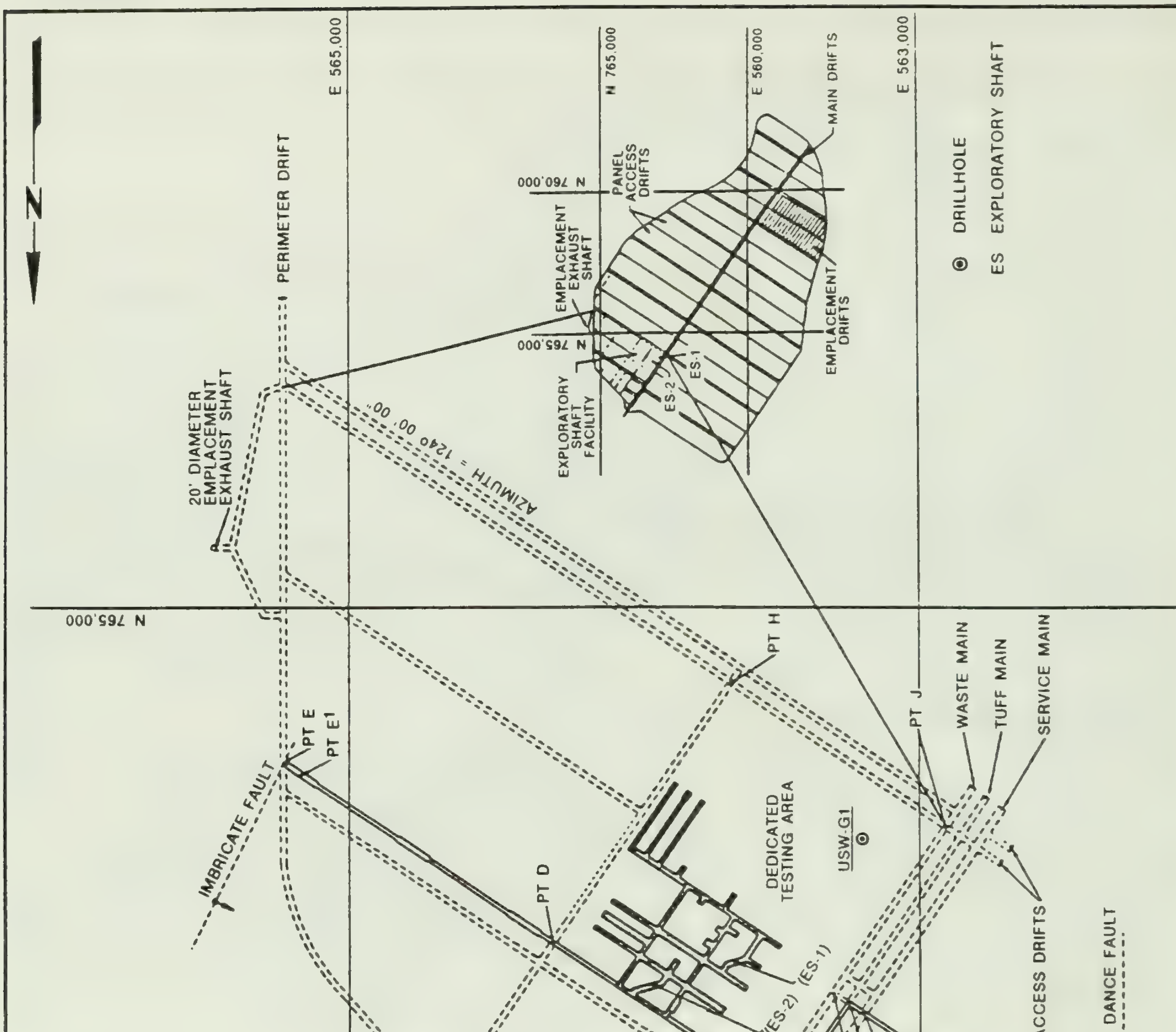



**Figure 8.4.2-4.** Conceptual repository layout in vicinity of the exploratory shaft facility dedicated test area and exploration drifts.

In general, the scientific testing activities planned for ES-1 will not be duplicated in ES-2. The primary purpose of the ES-2 is to provide support for the construction and operation of the ESF and not to provide additional access for site characterization. Existing data and the current understanding of the deposition of the volcanic units at the Yucca Mountain site and subsequent alteration indicate that the conditions in the host rock surrounding the two shafts should not vary significantly. Furthermore, the construction methods and, in most respects, the designs for ES-1 and ES-2 are the same. Therefore, the decision not to duplicate all ES-1 tests in ES-2 is consistent with the purpose of ES-2 and the information needs identified in performance allocation.

Two scientific tests that are planned in ES-2 are the perched-water test and the mapping of the shaft walls. The host rock intersected by ES-2 will be monitored for the presence of perched water during construction. This is consistent with the requirement from 10 CFR 60.15(d) that construction activities during site characterization not prevent the collection of needed data. Mapping activities in ES-2 are identical with those in ES-1 except for their scope. ES-2 mapping will include a complete photographic record identical to ES-1, but the detailed mapping along datum lines will be at greater intervals than in ES-1. Data from ES-2 will be used to statistically test the hypothesis that the rock conditions do not vary significantly between the two shafts. If this hypothesis is proved false, additional testing will be considered in ES-2.

In addition to the perched-water and mapping activities, observations will be made in ES-2 to assess the disturbance to the host rock around the shaft from construction.

In the next section, each of the 34 ESF test activities, including possible testing in the multipurpose borehole, is briefly described, as are the layout-related constraints imposed on the ESF design, construction, or operations. Present plans include drilling two multipurpose boreholes near ES-1 and ES-2 (Activity 8.3.1.2.2.4.9). The multipurpose boreholes planned near the ES-1 and ES-2 are discussed because they may be related to the ESF activities. The estimated zones of influence that must be accounted for in locating and conducting the tests are also described. The integrated data system, the ESF design, the construction operations, and the underground support systems planned for use in supporting the testing are described in Sections 8.4.2.3.2 through 8.4.2.3.5, respectively. Finally, the ESF layout and operations is evaluated in Section 8.4.2.3.6 relative to (1) the potential for interference between tests, (2) the potential for construction and operations interference with testing, (3) the integration of the ESF and the repository designs, (4) the design flexibility, and (5) the impact of safety concerns on the design and planned operations.

#### 8.4.2.3.1 Exploratory shaft facility testing operations, layout constraints, and zones of influence

Each of the presently planned ESF testing studies or activities listed in Table 8.4.2-12 is briefly described in the following sections from an operational and design perspective. These operational descriptions are

Table 8.4.2-12. Exploratory shaft facility tests (page 1 of 3)

| Test title | Test type[a] | SCP section | Lead organization[b] |
|---|---|---|---|
| Geologic mapping of the exploratory shaft and drifts | C, shaft<br>I,drifts | 8.3.1.4.2.2.4 | USGS/USBR<br>USBR |
| Fracture mineralogy studies of exploratory shafts and drifts | C, shaft<br>I, drifts | 8.3.1.3.2.1.3 | LANL |
| Seismic tomography and vertical seismic profiling | I | 8.3.1.4.2.2.5 | USGS/LBL |
| Shaft convergence | C | 8.3.1.15.1.5.1 | SNL |
| Demonstration breakout rooms | C | 8.3.1.15.1.5.2 | SNL |
| Sequential drift mining | I | 8.3.1.15.1.5.3 | SNL |
| Heater experiment in unit TSw1 | I | 8.3.1.15.1.6.1 | SNL |
| Canister-scale heater experiment | I | 8.3.1.15.1.6.2 | SNL |
| Yucca Mountain heated block | I | 8.3.1.15.1.6.3 | SNL |
| Thermal stress measurements | I | 8.3.1.15.1.6.4 | SNL |
| Heated room experiment | I | 8.3.1.15.1.6.5 | SNL |
| Development and demonstration of required equipment | I | 8.3.2.5.6 | SNL |
| Plate loading tests | I | 8.3.1.15.1.7.1 | SNL |
| Rock-mass strength experiment | I | 8.3.1.15.1.7.2 | SNL |
| Evaluation of mining methods | C,I | 8.3.1.15.1.8.1 | SNL |

Table 8.4.2-12. Exploratory shaft facility tests (page 2 of 3)

| Test title | Test type[a] | SCP section | Lead organization[b] |
|---|---|---|---|
| Evaluation of ground support systems | C,I | 8.3.1.15.1.8.2 | SNL |
| Monitoring drift stability | I | 8.3.1.15.1.8.3 | SNL |
| Air quality and ventilation | C,I | 8.3.1.15.1.8.4 | SNL |
| Shaft and borehole seals components testing | I | 8.3.3.2.2.3 | SNL |
| Overcore stress experiments in the exploratory shaft facility | C | 8.3.1.15.2.1.2 | USGS |
| Matrix hydrologic properties testing | C,I | 8.3.1.2.2.3.1 | USGS |
| Intact-fracture test in the exploratory shaft facility | C,I | 8.3.1.2.2.4.1 | USGS |
| Percolation tests in the exploratory shaft facility[c] | I | 8.3.1.2.2.4.2 | USGS |
| Bulk-permeability test in the exploratory shaft facility | I | 8.3.1.2.2.4.3 | USGS |
| Radial borehole tests in the exploratory shaft facility | C | 8.3.1.2.2.4.4 | USGS |
| Excavation effects in the exploratory shaft facility | C | 8.3.1.2.2.4.5 | USGS |
| Perched water test in the exploratory shaft facility (contingency test) | C | 8.3.1.3.2.4.7 | USGS |

Table 8.4.2-12. Exploratory shaft facility tests (page 3 of 3)

| Test title | Test type[a] | SCP section | Lead organization[b] |
|---|---|---|---|
| Hydrochemistry tests in the exploratory shaft facility | C,I | 8.3.1.3.2.4.8 | USGS |
| Diffusion tests in the exploratory shaft facility | I | 8.3.1.2.2.5 | LANL |
| Chloride and chlorine-36 measurements of percolation at Yucca Mountain | C,I | 8.3.1.2.2.2.1 | LANL |
| Engineered barrier system field tests | I | 8.3.4.2.4.4 | LLNL |
| Laboratory tests (thermal and mechanical) using samples obtained from the exploratory shaft facility | C,I | 8.3.1.15.1 | SNL |
| Hydrologic properties of major faults encountered in the main test level of the exploratory shaft facility | C | 8.3.1.2.2.4.10 | USGS |
| Multipurpose borehole testing near the exploratory shafts[d] | C | 8.3.1.2.2.4.9 | USGS |

[a]C = construction phase test, I = in situ phase test.
[b]USGS = U.S. Geological Survey, USBR = U.S. Bureau of Reclamation, LANL = Los Alamos National Laboratory, LBL = Lawrence Berkeley Laboratory, SNL = Sandia National Laboratories.
[c]This test used to be called the infiltration test.
[d]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.

followed by a discussion of potential interferences (constraints and zones of influence) that have been considered in locating each test. The interference evaluations were used to establish minimum requirements for separating the ESF tests from each other and from other mining operations.

The various tests planned for the exploratory shaft facility (ESF) are designed to acquire data on geologic, hydrologic, geomechanics, geochemical, and waste package environment characteristics. Strictly speaking, all tests performed in the ESF will be done in situ. The DOE, however, has classified those test activities that are initiated during construction of exploratory shaft 1 (ES-1) as construction-phase tests. Tests initiated on the main test level after ES-1 and ES-2 are connected, or elsewhere in the ESF after the shaft sinking tasks are completed, are termed in situ phase tests. The construction phase and in situ phase tests are identified in Table 8.4.2-12 along with references to test descriptions in Section 8.3. Section 8.3 provides the rationale for each test and information about how the resulting data will be used.

The extent of ESF testing could change from the tests presently identified and described in this document for several reasons. The ongoing prototype testing program, computer modeling, technical reviews, and/or improvements in instrumentation may result in future modifications to the tests. Also, the findings or performance of some of the early ESF tests, observations or measurements made in the multipurpose boreholes, or the conditions encountered in situ will probably result in some changes to present plans. Such changes will be approved and documented as they occur through the change-control process described in Section 8.4.2.3.3.1. Significant changes in the scope of existing tests, or new tests (including constraints, zones of influence and potential waste isolation impacts), will be described in the semiannual progress reports. Plans for testing in the ESF do not include the use of high-level radioactive materials or the introduction of radioactive artificial tracers. Radioactive sensors and sources will be used in planned testing, such as borehole geophysical logging, but are designed to be fully contained and retrievable. Any plans to use high-level radioactive materials or to introduce radioactive artificial tracers at the site will be included in SCP progress reports and will be subject to NRC review as specified by 10 CFR 60.18(e).

This section also describes the constraints imposed on the design by each individual test and the potential zone of influence each test may have on the surrounding region. Test constraints are essentially requirements imposed on the ESF design that must be satisfied to ensure that the test can be fielded properly. These constraints generally arise from experimental requirements that the in situ conditions (such as stress state, degree of saturation, or temperature in the region where the experiment is to be conducted) not be significantly altered by other activities in the ESF. How test constraints and interferences influence the ESF layout are discussed further in Section 8.4.2.3.6. Flexibility in choosing the final location of some experiments can be considered an important constraint because of local variations in geology and fracture orientation. The constraints that could impact the underground layout can generally be categorized into one of three main types:

1. Sequencing constraints, which may result from a requirement that the area supporting a particular test be developed early in the ESF construction because of the extended amount of time required to run the test or because the data from the test may be required before initiating other tests.

2. Physical location constraints, which may result from requirements for flexibility to choose alternate test locations based on specific test criteria and the need to conduct some tests in isolated areas in the main test level.

3. Construction and operational constraints, which generally arise from the requirement that tests be isolated from construction or mining activities because of their sensitivity to vibration, dust, and traffic.

Table 8.4.2-13 lists the general categories of test-related constraints that could impact the underground layout. Constraints that do not impact the layout are not in Table 8.4.2-13. For example, schedule constraints associated with the geologic mapping intended to occur routinely during ES-1 construction. Specific constraints and test requirements are discussed later in this section on a test-by-test basis.

Each experiment also alters or influences a surrounding region during the time the test is operational. This zone of influence becomes an important consideration in designing the main test level layout because of the requirements to separate experiments to avoid unacceptable test-to-test interference and to limit the zone of construction influence as much as possible to the dedicated testing area. The extent of the zone of influence for each test is a function of the time the test is operational (i.e., active data collection, generally taken to be the one- to two-year site characterization period) and principal alteration mechanisms resulting from the test. These mechanisms include (1) mechanically altered regions due to construction of drifts and alcoves for the experiment, including additional standoffs that may be required for instrumentation emplaced in the test drifts; (2) thermally altered regions due to emplacement of heaters to simulate heat loads expected from emplaced waste or to test thermomechanical properties of the rock; (3) hydrologically altered zones due to changing the in situ saturation state; and (4) geochemically altered zones due to the introduction of chemicals or by hydrothermal activity resulting from tests that heat the rock mass. The zones of influence for each test are determined from the time the test will be operational (i.e., active data collection) and the maximum extent of the principal alteration mechanism resulting from the test during the operational period.

Table 8.4.2-14 lists the principal factors (mechanism(s) considered in establishing a zone of influence for each test. Only the dominant driving mechanism(s) are given in this table even though some secondary or coupled mechanisms for altering the natural state were also considered in analyzing each test. For example, heating the rock mass also affects the local hydrological and stress conditions. Many of the tests planned for the ESF are designed to address coupled phenomena. For the purposes of establishing zones of influence for each test, however, the mechanism(s) that led to the

Table 8.4.2-13. Principal constraints imposed on the exploratory shaft facility layout by test requirements, listed by general category of constraint (page 1 of 3)

| Test | Sequencing | Physical location | Construction, operations | No constraints |
|---|---|---|---|---|
| Geologic mapping of the exploratory shaft and drifts | | | | X |
| Fracture mineralogy studies of exploratory shafts and drifts | | | | X |
| Seismic tomography and vertical seismic profiling | | | | X |
| Shaft convergence | X | | | |
| Demonstration breakout rooms | X | X | X | |
| Sequential drift mining | X | X | X | |
| Heater experiment in unit TSw1 | X | | | |
| Canister-scale heater experiment | | X | X | |
| Yucca Mountain heated block | | X | X | |
| Thermal stress measurements | X | X | X | |
| Heated room experiment | X | X | X | |
| Development and demonstration of required equipment | | TBD[a] | TBD | |
| Plate loading tests | | X | | |

Table 8.4.2-13. Principal constraints imposed on the exploratory shaft facility layout by test requirements, listed by general category of constraint (page 2 of 3)

| Test | Sequencing | Physical location | Construction, operations | No constraints |
|---|---|---|---|---|
| Rock mass strength experiment | | | | X |
| Monitoring drift stability | | | | X |
| Air quality and ventilation | | | | X |
| Evaluation of mining methods | | | | X |
| Evaluation of ground support systems | | | | X |
| Seal components testing | TBD | TBD | TBD | TBD |
| Overcore stress experiments | | X | X | |
| Matrix hydrological properties testing | | | | X |
| Intact-fracture test | | | | X |
| Percolation tests | | X | X | |
| Bulk permeability test | | X | X | |
| Radial borehole tests | | | | X |
| Excavation effects test | | | | X |
| Perched water test | | | | X |
| Hydrochemistry test | | | | X |

Table 8.4.2-13. Principal constraints imposed on the exploratory shaft facility layout by test requirements, listed by general category of constraint (page 3 of 3)

| Test | Sequencing | Physical location | Construction, operations | No constraints |
|---|---|---|---|---|
| Diffusion test | | X | | |
| Chloride and chlorine-36 measurements | | | | X |
| Engineered barrier system field test (waste package test) | | X | X | |
| Laboratory tests of geoengineering properties | | | | X |
| Hydrologic properties of faults | | X | X | |
| Multipurpose boreholes[b] | X[c] | X[c] | | |

[a]TBD = to be determined.
[b]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.
[c]Constraints are based on a preliminary evaluation of multipurpose borehole concepts.

Table 8.4.2-14. Categories of effects considered in evaluating the zone of influence for each site characterization test (page 1 of 3)

| Test | Mechanical[a] | Thermal[b] | Hydrologic[c] | Chemical[d] | No effects[e] |
|---|---|---|---|---|---|
| Geologic mapping of the exploratory shaft and drifts | | | | | X |
| Fracture mineralogy studies of exploratory shafts and drifts | | | | | X |
| Seismic tomography and vertical seismic profiling | | | | | X |
| Shaft convergence | X | | | | |
| Demonstration breakout rooms | X | | | | |
| Sequential drift mining | X | | | | |
| Heater experiment in unit TSw1 | | X | | | |
| Canister-scale heater experiment | | X | | | |
| Yucca Mountain heated block | X | X | | | |
| stress measurements | X | X | | | |
| Heated room experiment | X | X | | | |
| Development and demonstration of required equipment | | | | | X |
| Plate loading tests | X | | | | |
| Rock mass strength experiment | X | | | | |

Table 8.4.2-14. Categories of effects considered in evaluating the zone of influence for each site characterization test (page 2 of 3)

| Test | Mechanical[a] | Thermal[b] | Hydrologic[c] | Chemical[d] | No effects[e] |
|---|---|---|---|---|---|
| Monitoring drift stability | | | | | X |
| Air quality and ventilation | | | | | X |
| Evaluation of mining methods | | | | | X |
| Evaluation of ground support systems | | | | | X |
| Seal components testing | | | To be determined | | |
| Overcore stress experiments | | | | | X |
| Matrix hydrological properties testing | | | | | X |
| Intact-fracture test | X | | | | |
| Percolation tests | X | | X | | |
| Bulk permeability test | X | | X | | |
| Radial borehole tests | | | X | | |
| Excavation effects test | | | | | X |
| Perched water test | | | | | X |
| Hydrochemistry tests | | | | | X |
| Diffusion tests | | | | X | |

Table 8.4.2-14. Categories of effects considered in evaluating the zone of influence for each site characterization test (page 3 of 3)

| Test title | Mechanical[a] | Thermal[b] | Hydrologic[c] | Chemical[d] | No effects[e] |
|---|---|---|---|---|---|
| Chloride and chlorine-36 measurements | | | | | X |
| Engineered barrier system field tests (waste package test) | X | X | | | |
| Laboratory tests of geoengineering properties | | | | | X |
| Hydrologic properties of faults | x | | x | | |
| Multipurpose boreholes[f] | x[g] | | | | |

[a]Mechanical effects include stress alteration due to the drifting required for the test as well as due to the test itself and potential interferences from instrumentation arrangement. The effects do not explicitly include rock damage resulting from the controlled blasting mining method or stress alterations due to general construction in the exploratory shaft facility; these construction effects are considered in the discussions of constraints related to standoff from service drifts that provide access to the testing areas.

[b]Thermal effects include coupled effects resulting from the addition of heat; e.g., vapor movement resulting from heating

[c]Hydrologic effects include only the effects from the fluids added to the formation by the test. Fluids used in construction are not included.

[d]Chemical effects include the effects from tracers in fluids used in construction and in chemical analyses of explosives and by-products resulting from blasting materials.

[e]No effects means no physical mechanism was identified that would cause additional perturbation to the natural condition (stress, temperature, moisture, etc.) from conducting this test. Test may be primarily observational or laboratory based with only sample collection activities in the underground excavations.

[f]Multipurpose boreholes MP-1 and MP-2 are described in Section 8.3.1.2.2.4.9.

[g]Zone of influence is based upon a preliminary evaluation of multipurpose borehole concepts.

establishment of the most pervasive zone was considered the principal mechanism, with the influence of secondary mechanisms falling within or coincident with the zones established by the principal mechanism. These principal mechanisms are given in Table 8.4.2-13. In some instances, no physical mechanism was identified that would cause additional perturbation to the natural conditions (stress, temperature, moisture, etc.) from conducting the test. In these cases the principal mechanism in Table 8.4.2-13 is listed as none. The table also lists tests, such as the proposed seal components testing, where the zone of influence is to be determined (TBD). Even though concepts exist for these tests, they are not sufficiently developed at this time to establish a zone of influence. As the designs of these tests progress, interferences related to them will be analyzed and zones of influence established. These will be documented in the semiannual progress reports.

In establishing the constraints and zones of influence for each test, only test-related alterations to the local conditions were considered. That is, the alteration of the natural conditions due to normal mining and construction of ESF shafts and drifts was not considered part of the potential zone of influence of the test. Effects of construction are considered in the discussions of constraints related to standoff from support drifts that provide access to the experiment drifts. Only when special controls (over and above the strict controls already planned for use during construction) on the use of water or chemicals are required to perform a test, are they listed as additional constraints to the design.

These elements of construction and operation that have potential for interference with testing are addressed in more detail in Section 8.4.2.3.6.2. But four general points regarding these potential effects of construction on the ESF test program and their relationship to the test related zones of influence are noted here for completeness. First, there will be stringent controls on the construction methods used throughout the underground excavations. For example, drill and blast specifications will include controls related to types and amounts of explosives, shot pattern, hole depth, etc. Water use will be part of specifications for drilling, dust control, cleaning of walls for geologic mapping, and other appropriate activities. If the standard, stringent, controls planned for use in most areas of the ESF are expected to suffice for control of water and chemical agents near a particular test, they are not mentioned specifically as a test-related constraint on the design. Only for those tests that may require additional controls are constraints noted. The effect of construction activities on the nearby rock mass has been estimated from the preliminary evaluations of West, 1988, as summarized in 8.4.3.2. The by-products from construction blasting have been estimated to penetrate 1 to 1.5 m into the drift and shaft walls. In addition, construction water is estimated to penetrate, in general, less than 10 m into the formation (Section 8.4.2.3.6.2). While not specifically mentioned in Section 8.3 of the SCP, a significant number of instruments will be grouted in place. The geochemical effects of this grout are expected to be very localized (Fernandez et al., 1988). The potential zones of influence resulting from these mechanisms are within or approximately equivalent to the zone of influence of the shafts drifts established as a result of mining induced stress alteration (Hill, 1985; Thomas, 1987; Costin and Bauer, 1988; Zimmerman et al., 1988). Therefore, a two drift diameter minimum lateral standoff was established

between drifts and between the ESF and the repository drifts to preclude interference due to mining.

Second, work is in progress to establish a basis for determining the necessary controls on water and blasting methods used in the underground excavations. These studies will also help determine the effects construction water and explosive products may have on the hydrological and chemical tests to be performed on rock samples taken during construction. Specific controls on the quantity and types of explosives that can be used without affecting planned tests are to be determined from this effort.

Third, as indicated in Section 8.4.1, the early testing and observations in the ESF will provide data that can be used to confirm or redefine the estimates of the zones of influence from the principal mechanisms discussed previously. The radial boreholes test will provide early data on the changes in saturation near the shafts. The multipurpose boreholes also would provide early data on changes in saturation near the shafts. The shaft convergence test and the tests in the demonstration breakout rooms will provide data on the stress-altered zone around the shafts and drifts that can be compared with predictions. The heater tests in the upper demonstration breakout room will help define the expected thermal zones and assist in establishing the extent of the coupled hydrologic zone due to the heating. Therefore, there should be sufficient data available early in the testing program and sufficient flexibility in the design layout (Section 8.4.2.3.6.4) to allow for correction of new interferences that may be identified as construction proceeds.

Finally, while every effort is being made to ensure that the test environment in the ESF is compatible with the experimental requirement, there are many uncertainties associated with underground, in situ experimentation that designers and experimenters cannot control. Unlike a laboratory setting, an underground mine environment is inherently a dirty, noisy, and potentially dangerous place to work. Rock properties and conditions are variable and, despite the most careful and complete design and analysis effort, the complete success of each and every test planned for the ESF cannot be guaranteed.

An example of the uncertainties of in situ testing is given by the experience encountered in the prototype testing conducted in G-Tunnel on the Nevada Test Site. In both the heated block test (Zimmerman et al., 1986a) and the mining effects tests (Zimmerman et al., 1988), changes had to be made in the testing procedures or instrument locations based upon observations made during construction and testing.

The design is developed to provide the most favorable conditions possible for conducting the proposed testing by satisfying the test constraints and by ensuring that the zones of influence of each test and the ESF construction do not lead to significant interference problems. There are, however, many uncertainties involved with in situ testing, such as those just noted, that cannot be addressed directly in the design. Thus, a large amount of flexibility is included in the design, layout, and the operational aspects of the ESF. Including sufficient flexibility in the design (as discussed in Section 8.4.2.3.6.4), should allow many of the potential problems resulting from the uncertainties of in situ testing to be overcome.

Following are brief descriptions of the purpose and operational procedure for each test, including a discussion of the constraints to the design that have been identified (Table 8.4.2-13) needed to properly conduct the test. Also included are the estimates of the zone of influence of each test resulting from the mechanisms identified in Table 8.4.2-14. These constraints and zones of influence form the bases for the design evaluation described in Sections 8.4.2.3.2 through 8.4.2.3.5; this evaluation is presented in Section 8.4.2.3.6.

Activity: Geologic mapping of exploratory shafts and drifts (Section 8.3.1.4.2.2.4)

Purpose and operations

Geologic mapping and photogrammetry will be used to document lithologic and fracture variability throughout the vertical and horizontal extent of the underground excavations, to investigate structural features, and to provide siting data to confirm (or modify) planned test locations within the underground excavations. As discussed in the introduction to Section 8.4.2.3, it is planned that the ES-1 and ES-2 shafts will be mapped using the same techniques. A complete photographic record will be obtained in both shafts. The detailed mapping along datum lines will be at greater intervals in ES-2 than ES-1. Where stratigraphic contacts occur or where geologic anomalies are encountered in ES-2, the mapping detail will be comparable in both shafts.

Included in this activity are cleaning the shaft or drift wall areas using minimal amounts of water (i.e., less than that used for dust control), surveying in reference points, and marking significant structural features. Geologists will map the exposed wall interval as described in Section 8.3 and make a permanent record of the wall rock by using twin cameras to obtain high-resolution, stereo photographs referenced to the surveyed bearings. Finally, the geologists will collect, package, and label hand specimen samples for geologic, mineralogic, petrologic, geochemical, geomechanical, or hydrochemical analyses and for archival storage.

Constraints and zones of influence

This activity is primarily observational (photogrammetric mapping) and will be conducted in the underground excavations as construction proceeds. Because it is observational, no special constraints are required to include this activity in the ESF testing, and no additional, significant perturbation to natural conditions (stress, temperature, moisture, etc.) will result from the mapping activities (that is, there is no significant zone of influence).

Activity: Fracture mineralogy studies of exploratory shaft and drifts (Section 8.3.1.3.2.1.3)

Purpose and operations

The fracture mineralogy studies will be conducted to determine mineralogic variability throughout the vertical section of ES-1, to establish the time and conditions of fracture mineralogy deposition alteration, and to

identify fracture-coating mineral types, sorptive characteristics, and health hazard potential of fibrous zeolites.

In addition to mineralogic sampling of drill core and rubble collected at the working face in the shaft and drifts, samples will be collected on the surface from the muck removed. The muck will be segregated, either in a temporary surface storage bin or at the muck storage area, and the geologists will hand pick samples for fracture-coating mineralogy studies. The samples will be packaged and labeled for shipment to a laboratory for detailed analyses, including age determinations.

Constraints and zones of influence

Stratigraphy and variability of the devitrified Topopah Spring Member. This activity involves sample collection and subsequent laboratory examination of rock from the underground excavations where a variety of geologic conditions are expected to be encountered. Because only sample collection is involved, no special constraints are required to conduct this activity in the ESF, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity. No significant zone of influence results from this activity.

Mineralogy of fractures and faults. This activity involves sample collection and subsequent laboratory examination of rock from ES-1 and ES-2, the dedicated test area, and the long exploratory drifts where a variety of geologic conditions are expected. Because only sample collection is involved, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity. No significant zone of influence results from this activity.

Activity: Seismic tomography and vertical seismic profiling (Section 8.3.1.4.2.2.5)

Purpose and operations

The purpose of seismic tomography and vertical seismic profiling tests is to evaluate or develop a method for remote characterization of subsurface fracture networks using the ESF tests as a means to calibrate against mapped fracture networks.

When fracture domains are selected in the shaft or drifts as described in Section 8.3.1.4.2.2.5, short boreholes will be drilled (or existing holes used) to install geophones or similar instrumentation. When the sensor arrays are in place, seismic stimuli will be initiated by using explosives or vibroseis techniques at surface locations selected by the investigators.

Constraints and zones of influence

This activity will use surface drilled boreholes and short ($\leq 3$ m long) boreholes in the underground excavations to install seismic sensors. No special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature,

moisture, etc.) will result from this activity (i.e., no significant zone of influence results from this activity).

Activity: Shaft convergence (Section 8.3.1.15.1.5.1)

Purpose and operations

Shaft convergence tests will be used to monitor rock-mass deformation around the shaft opening and measure in situ horizontal stress.

Using standard overcore techniques (Section 8.3.1.15.2.1.2), horizontal stress measurements will be made at each of three test locations in ES-1 as the shaft is being sunk.

Rock-mass deformation around the ES will be monitored at three measurement stations consisting of two levels separated by several meters, using multiple-point borehole extensometers (MPBXs) placed at 120° intervals around the shaft circumference (Figure 8.4.2-5). The MPBXs will be installed as soon as practicable after excavation of the relevant level in the ES. Deformations will be measured across the shaft diameter and as a function of distance from the shaft at multiple locations in the walls. The MPBX heads will not be covered by the shaft liner, so that the deformations can be monitored as a function of time. In addition to MPBX measurements, deformations will be measured with rod extensometers at each of the three measurement stations. Extensometer measurements will be made along diameters in the same plane as the MPBXs at 60° from the MPBX heads.

Hydraulic pressure cells will be installed in the shaft liner to monitor radial stress changes over time as shaft sinking continues below the test location.

Constraints and zones of influence

This experiment will be conducted during the construction phase of ES-1. Constraints include the requirement for some flexibility in locating the tests near the three depths at which the tests are planned. Reasonably competent rock is required at the test horizon to ensure proper gage installation.

A mechanical zone of influence is created because horizontal MPBX gages will be used at each measurement station. These gages are anchored 15 m from the shaft wall. Care should be taken that any vertical boreholes from the demonstration breakout rooms do not pass within four hole diameters of the MPBX gauge holes to ensure that the anchors remain fixed in the rock. The zone of geochemical alteration resulting from the use of grout in the MPBX gauge holes is expected to be very small and governed by molecular diffusion. Analyses by Birgersson and Neretnicks (1982) indicate that this zone would be 0.3 ft for 3 to 12 months.

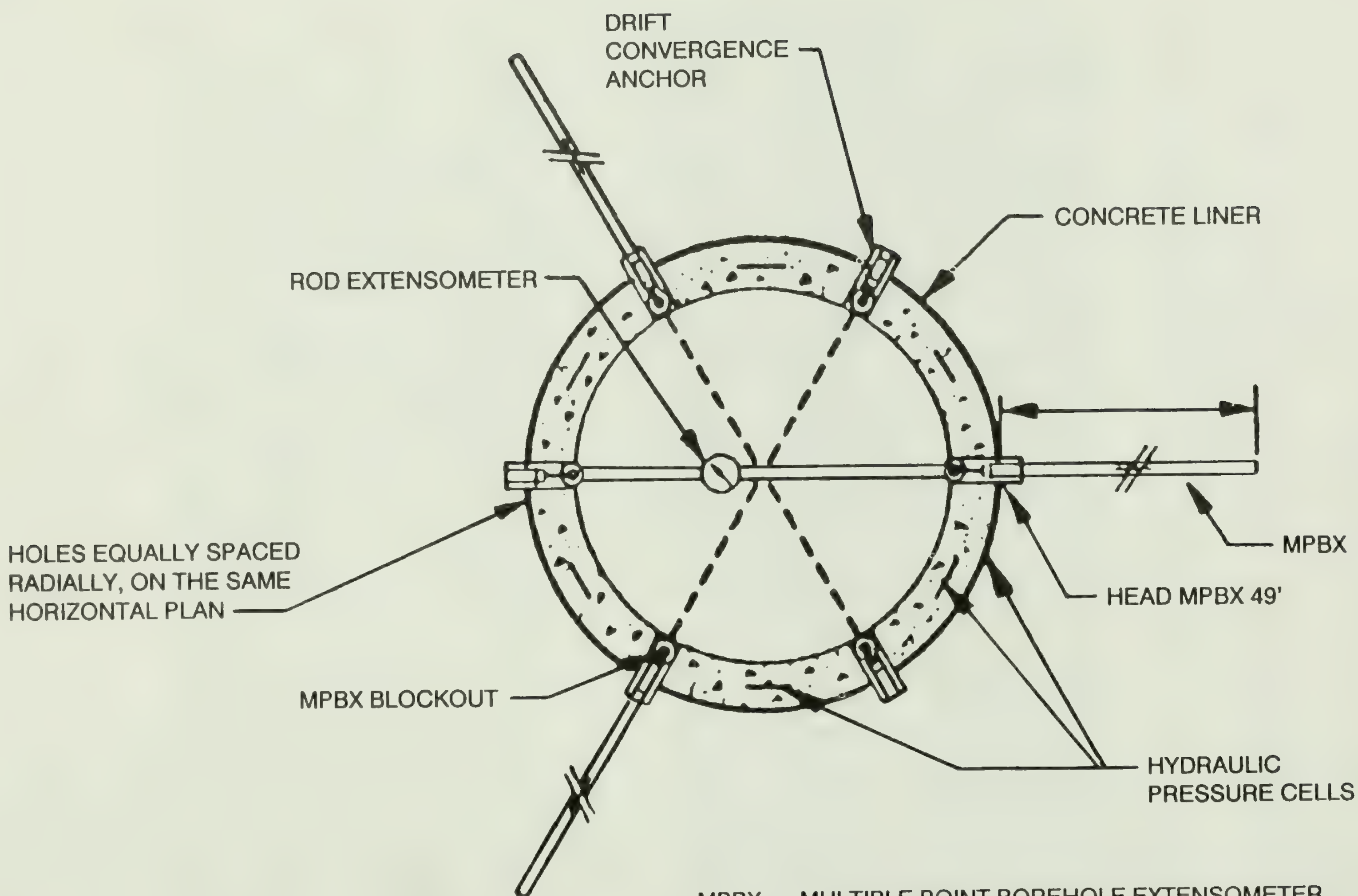



**Figure 8.4.2-5.** Measurement details of the shaft convergence test.

Activity: Demonstration breakout rooms (Section 8.3.1.15.1.5.2)

Purpose and operations

These tests will be used to demonstrate constructability and stability of drift openings in the upper lithophysal zone of the Topopah Spring member (PTn) in the upper demonstration breakout room (UDBR) and in welded fractured tuff on the main test level.

At the UDBR shown in Figure 8.4.2-6 and in the breakout room at the main test level, mined openings will be sized to be consistent with the maximum width planned for repository drifts. Optimum blasting methods in each DBR horizon and rock stabilization requirements and techniques will be determined. Rock mass response will also be measured in the DBR excavations by using extensometers and convergence anchors.

Constraints and zones of influence

Flexibility in the orientation of the rooms is required to insure that desired alignment relative to local geological features, such as the prevailing joint structure, is achieved. This is important because one use of the data derived from this experiment will be for evaluation of structural computer models. Proper alignment of the drift is required to limit the potential for variability of the mechanical response along the drift so that models can be more effectively used to represent the excavation in computer calculations. Other constraints include a requirement that no other mining should be allowed within a distance of approximately 50 ft from the deepest MPBX anchors installed in the drift walls while the experiment is in progress. MPBX gages are anchored 50 ft into the drift walls. If other mining takes place within 50 ft of the bottom anchor (100 ft from drift wall), the MPBX anchor positions may be disturbed.

The main test level-DBR (or lower DBR) shown in Figure 8.4.2-7 is to be mined before any repository drift development of the dedicated test area of the ESF. Baseline testing should be complete before proposed drifts within the required standoff region are mined. Within the constraints of adjacent drifts, a zone of flexibility is defined such that the stress altered zone due to mining will not affect other drifts that may be mined later. The lower DBR may be oriented within a 40 degree shaped fan contained in the area set aside for the drift off of ES-2. This results in a potential zone of influence (stress altered region) extending 50 ft (two drift diameters) to either side of the flexibility area (Costin and Bauer, 1988). Because the lower DBR will be mined first, initial displacement measurements will not be affected by other activities.

No zones of thermal or hydrological alteration will result from this test because no heat or water are used in the test. The zone of geochemical alteration resulting from the use of grout in the MPBX gage holes is expected to be very small and governed by molecular diffusion. Analyses by Birgersson and Neretnicks (1982) indicate that this zone would be 0.3 ft for 3 to 12 months.

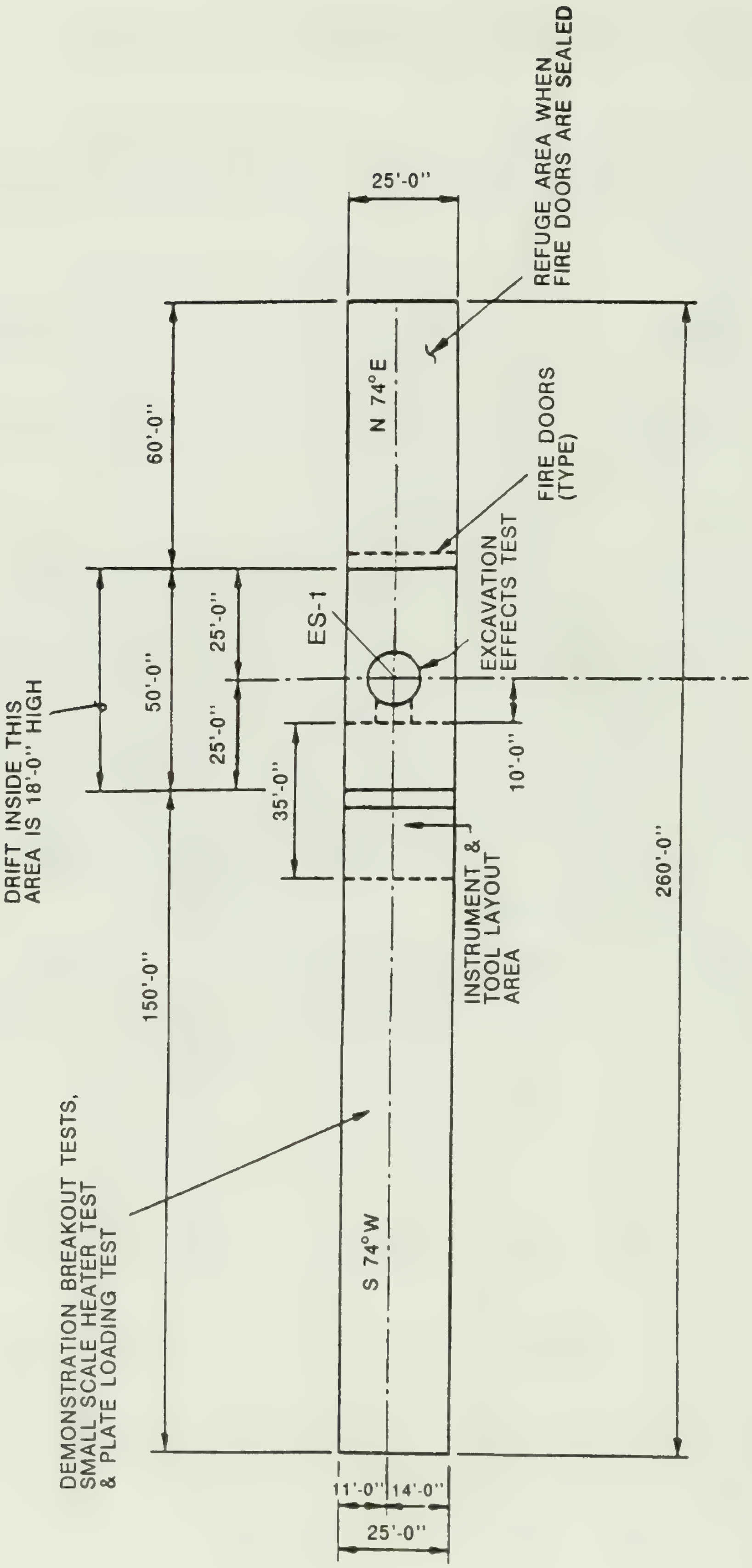



**Figure 8.4.2-6.** Plan view of the upper demonstration breakout room. Modified from Title I design package (DOE, 1988)

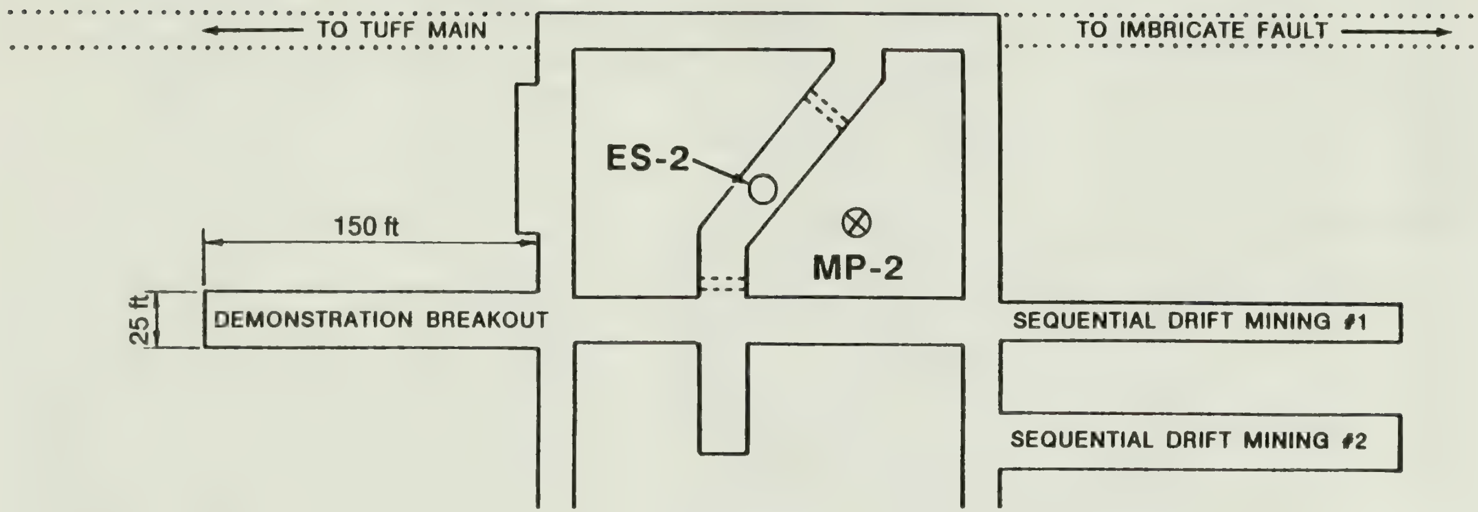



**Figure 8.4.2-7.** Main test level demonstration breakout room. Modified from Title I design package (DOE, 1988).

Activity: Sequential drift mining (Section 8.3.1.15.1.5.3)

Purpose and operations

The purpose of sequential drift mining is to obtain deformation response data in rock surrounding a repository-size drift opening as it is being mined in the dedicated test area.

Two parallel instrumentation drifts will be mined as shown on Figure 8.4.2-8. Instrumentation holes will be drilled to monitor above, below, and adjacent to a central third parallel drift as shown conceptually in Figure 8.4.2-9. Borehole sensors will be installed to monitor stress release, bulk permeability changes, and deformation. To measure rock mass response to mining, baseline data will be obtained before mining of the center parallel drift. Air and water permeability in boreholes adjacent to the new drift opening will be measured after mining.

Constraints and zones of influence

Flexibility in location and orientation of the drifts is desired because the results of this experiment will be used to evaluate structural computer models. Mining should be planned such that no mining, other than construction of the center parallel drift, will be conducted within a standoff distance of approximately two drift diameters from the edge of the instrumentation drifts while the test is in progress. This standoff distance, ensures that the construction of other drifts will not alter the deformations and stress state near the experimental drift during the testing period (Zimmerman et al., 1988). Because long-term monitoring of ground support in the sequential drift mining test is required, subsequent mining within the standoff zone must be avoided.

No thermal zone of influence will result from this activity. The small amounts of air and water that may be injected into the rock mass between the drifts for permeability testing is not expected to alter the hydrological conditions more than 1 to 2 m from the boreholes. The zone of geochemical alteration resulting from using grout in the gage holes is expected to be very small and governed by molecular diffusion. Analyses by Birgersson and Neretnicks (1982) indicate that this zone would be 0.3 ft for 3 to 12 months.

Within the area between adjacent drifts, a zcne of flexibility is defined such that the stress altered zone due to mining will not affect other drifts that may be mined later. Drifts may be oriented within a 60 degree shaped fan (±30 degrees from the proposed centerline orientation) or the entire configuration may be reoriented to a direction parallel to the panel access drifts (perpendicular to the configuration shown in the Title I design layout). This results in a potential mechanical zone of influence extending 30 ft (two access drift diameters) to either side of the flexibility zone (Costin and Bauer, 1988 and Zimmerman et al., 1988). Once the drift direction is determined, the zone of influence can be narrowed; that is, additional area required by the necessary flexibility is eliminated.

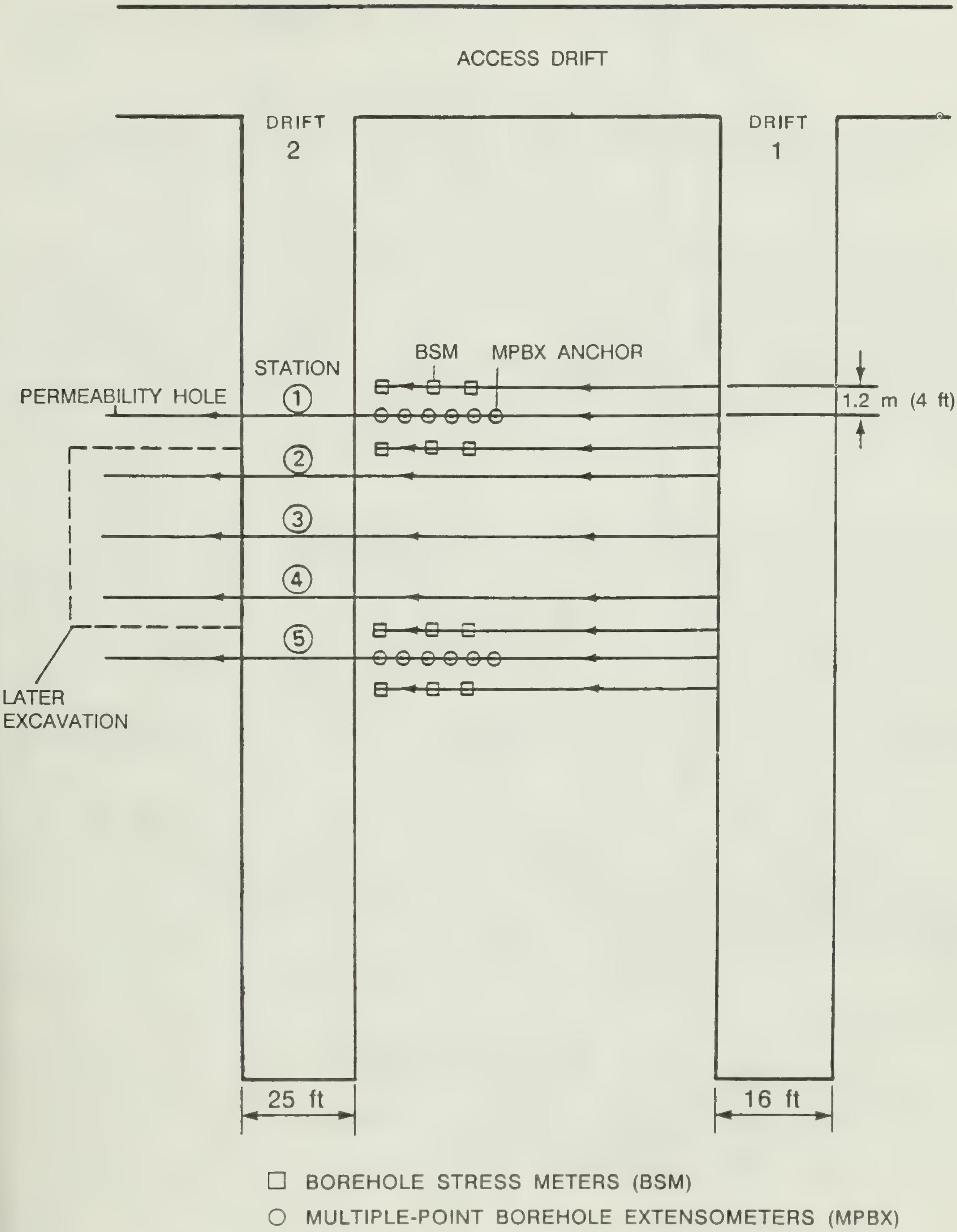
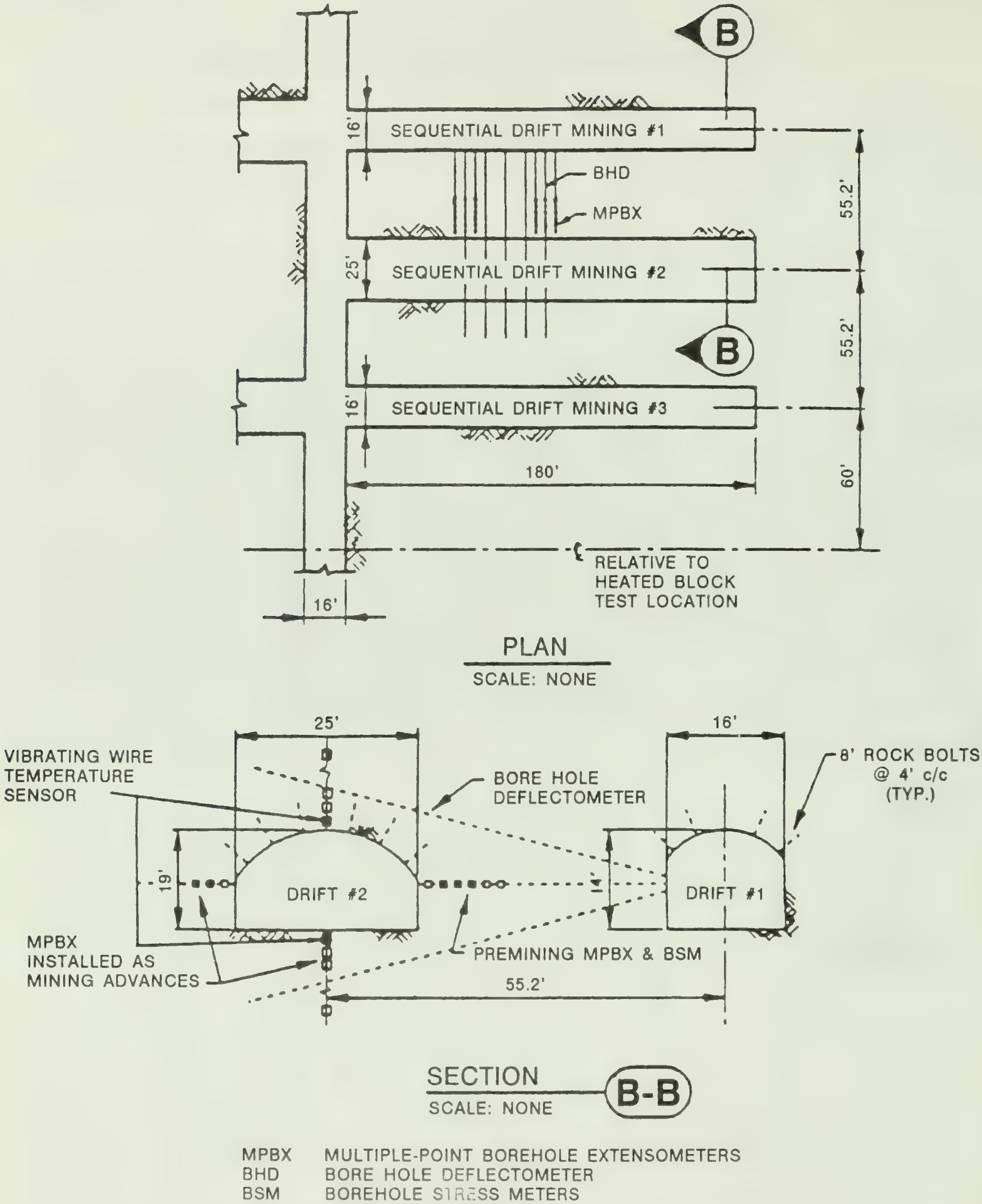



**Figure 8.4.2-8.** Sequential drift mining tests.




**8.4.2-9.** Sequential drift mining test. Modified from Title I design package (DOE, 1988).

Activity: Heater experiment in unit TSw1 (Section 8.3.1.15.1.6.1)

Purpose and operations

The purpose of the heater experiment is to establish thermomechanical and thermally induced hydrologic responses in high-lithophysal rock to verify scaling relationships needed for repository design and performance calculations.

In the upper demonstration breakout room (UDBR), a heater-emplacement hole will be drilled approximately 8 ft (2.4 m) into the drift wall as shown conceptually in Figure 8.4.2-10. Several instrumentation holes parallel to the heater hole will be drilled and then heater and instruments (multiple point borehole extensometers (MPBX) and thermocouples) will be installed. In a borehole near the heater, neutron logs will be run before, during, and after the heating cycle to monitor moisture content changes. After the heater is started, the rock response to thermal loading, heat flow, and moisture changes will be monitored.

Constraints and zones of influence

This test will be conducted in the upper DBR and is intended to measure rock mass thermal properties, in situ water content changes due to heating and thermal expansion in the lithophysae-rich tuff. Because the test is short (approximately one month) and affects only a small amount of rock (0.3 $m^3$) (Zimmerman et al., 1986b), no special constraints are required. Sufficient flexibility exists to locate the test so that other activities in the UDBR are not adversely affected.

Activity: Canister-scale heater experiment (Section 8.3.1.15.1.6.2)

Purpose and operations

The canister-scale heater experiment will monitor thermomechanical and hydrothermal responses in the repository host rock at canister scale for design and performance modeling, for the investigation of retrievability, and for the monitoring of radon emanation as a function of heat loading. During the tests, heat fluxes will be increased so that temperatures near the canister heater exceed design limits. This phase of the test is to aid in determining limits on waste-emplacement borehole stability.

At a location within the dedicated area, a 13 in. (0.37 m) diameter hole will be drilled 20 ft (6.1 m) into a drift wall. Parallel small-diameter instrumentation holes (Figure 8.4.2-11) will be drilled. Baseline moisture data in neutron probe holes will be recorded. A heater and instrumentation (thermocouples, MPBXs, borehole deformation gages, and radon monitors) will be installed. Finally, heating steps will be initiated, and thermal, thermomechanical, and hydrothermal phenomena, and radon release rates, will be monitored at increasing heat loads.

Constraints and zones of influence

To limit the influence of drift openings (1) on the stresses near the heater and (2) on the temperatures produced in the rock formation, the heater

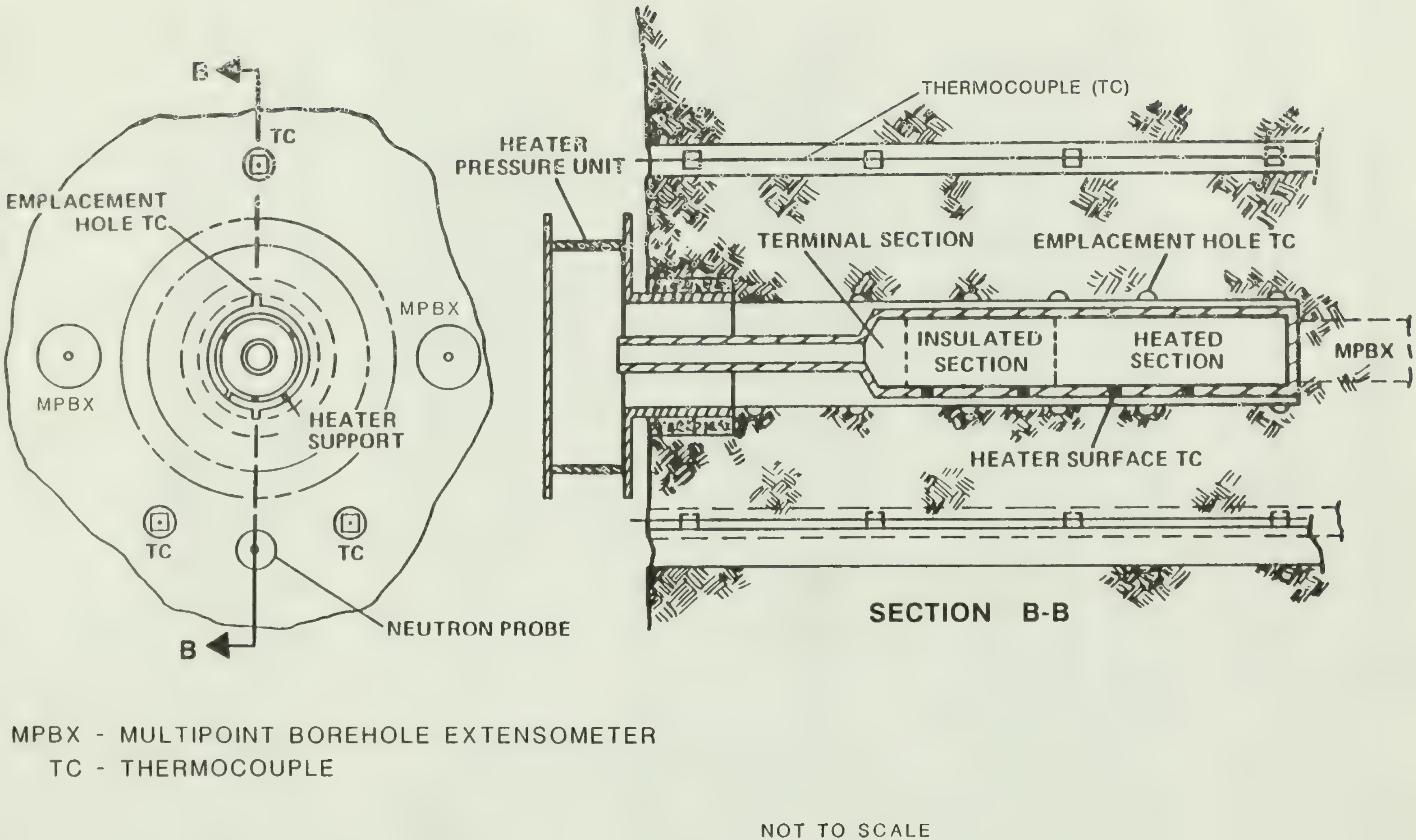



**Figure 8.4.2-10.** Conceptualized elevation view of heater experiment in TSwl (lithophysal Topopah Spring unit) Modified from Title I design package (DOE, 1988).

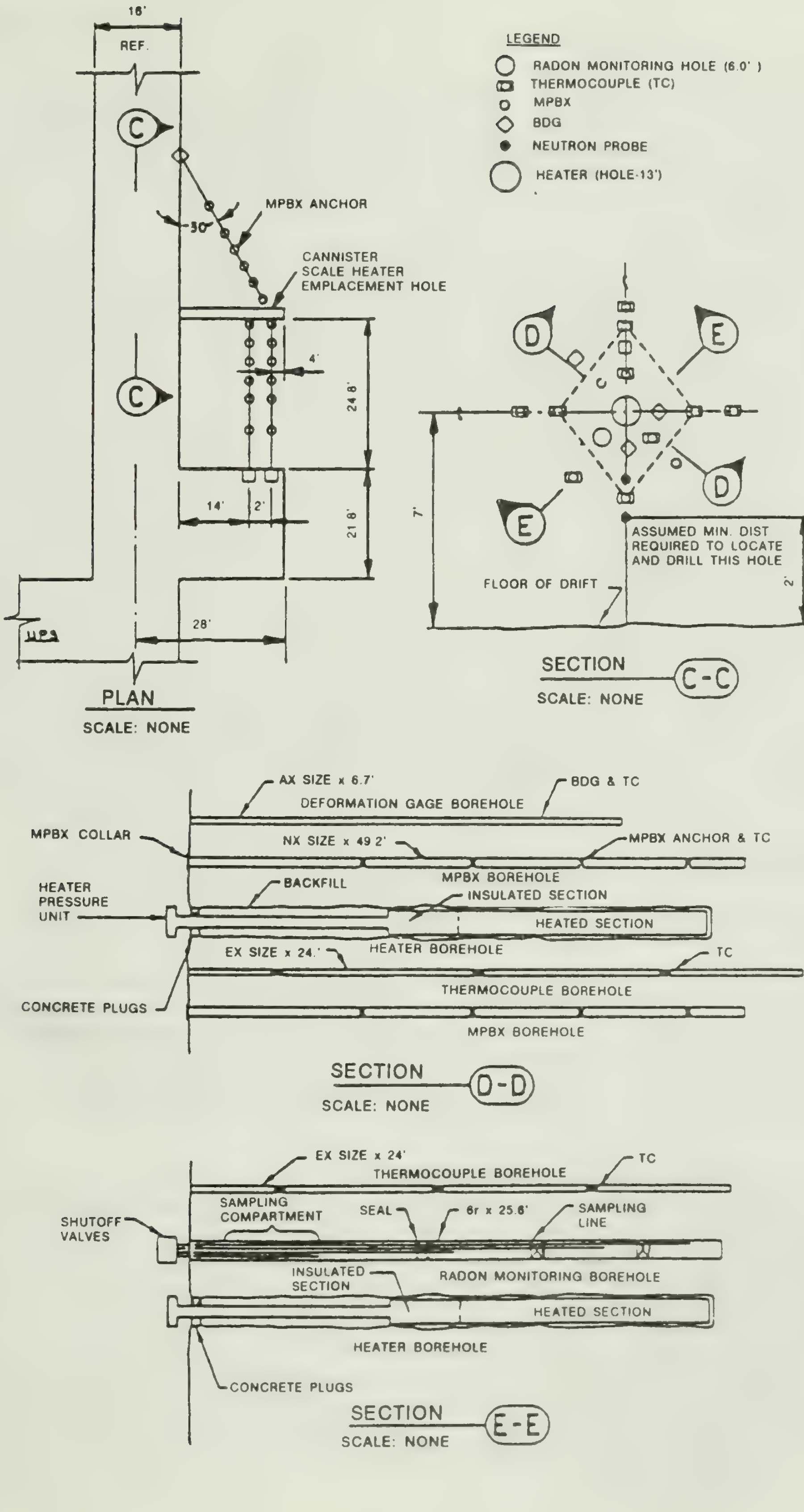



**Figure 8.4.2-11.** Canister scale heater test. Modified from Title I design package (DOE. 1988).

should be located a minimum of 9 m (based on Bauer et al., 1988) from drifts or alcoves running parallel to the axis of the heater. The experiment needs to be located in a low traffic area because the rock surface near the heater emplacement hole will reach temperatures in excess of 200°C and may pose a hazard to personnel in the area.

At 30 months, the 100°C isotherm will be approximately 5 m radially from the center of the canister (Bauer et al., 1988). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending to a maximum of 10 m beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region extending up to 14 m radially from the heater may be created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 14 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). The 35°C isotherm (4°C above expected ambient temperature) will attain a maximum distance of 15 m radially from the heater and 20 m from the emplacement drift wall along the axis of the heater (Bauer et al., 1988), resulting in a thermal zone of influence of approximately 30 m by 20 m. Therefore, both the zones of potential chemical and hydrological alteration are expected to be contained within the zone of thermal alteration. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stress should not be more than 10 percent above the initial in situ stress (Bauer et al., 1988).

Activity: Yucca Mountain heated block (Section 8.3.1.15.1.6.3)

Purpose and operations

The Yucca Mountain heated block experiment will (1) measure three-dimensional deformation and temperature changes; (2) measure relationships among fracture permeability, stress, and temperature; (3) monitor moisture movement relative to temperature; and (4) evaluate cross-hole measurement methods in large blocks of welded tuff. Results from 1, 2, and 3 will be used in modeling.

At a selected location in the dedicated test area, an alcove will be mined and a 6 ft by 6 ft (2 m by 2 m) area of rock will be defined within the alcove. Baseline fracture permeabilities will be measured, reference survey pins will be established, and crosshole ultrasonic measurements will be made. Next, slots will be cut on each side of the block approximately 6 ft (2 m) deep and flatjacks will be inserted. An array of heaters will be installed in holes on opposite sides of the block as shown in Figure 8.4.2-12. Other instrumentation holes will be drilled and instrumented with thermocouples, MPBXs, and deformation gages. Finally, cyclic tests will be conducted at various mechanical loads (imposed using flatjacks) and thermal loads (imposed using heaters). The rock responses and permeability changes under induced conditions will be monitored.

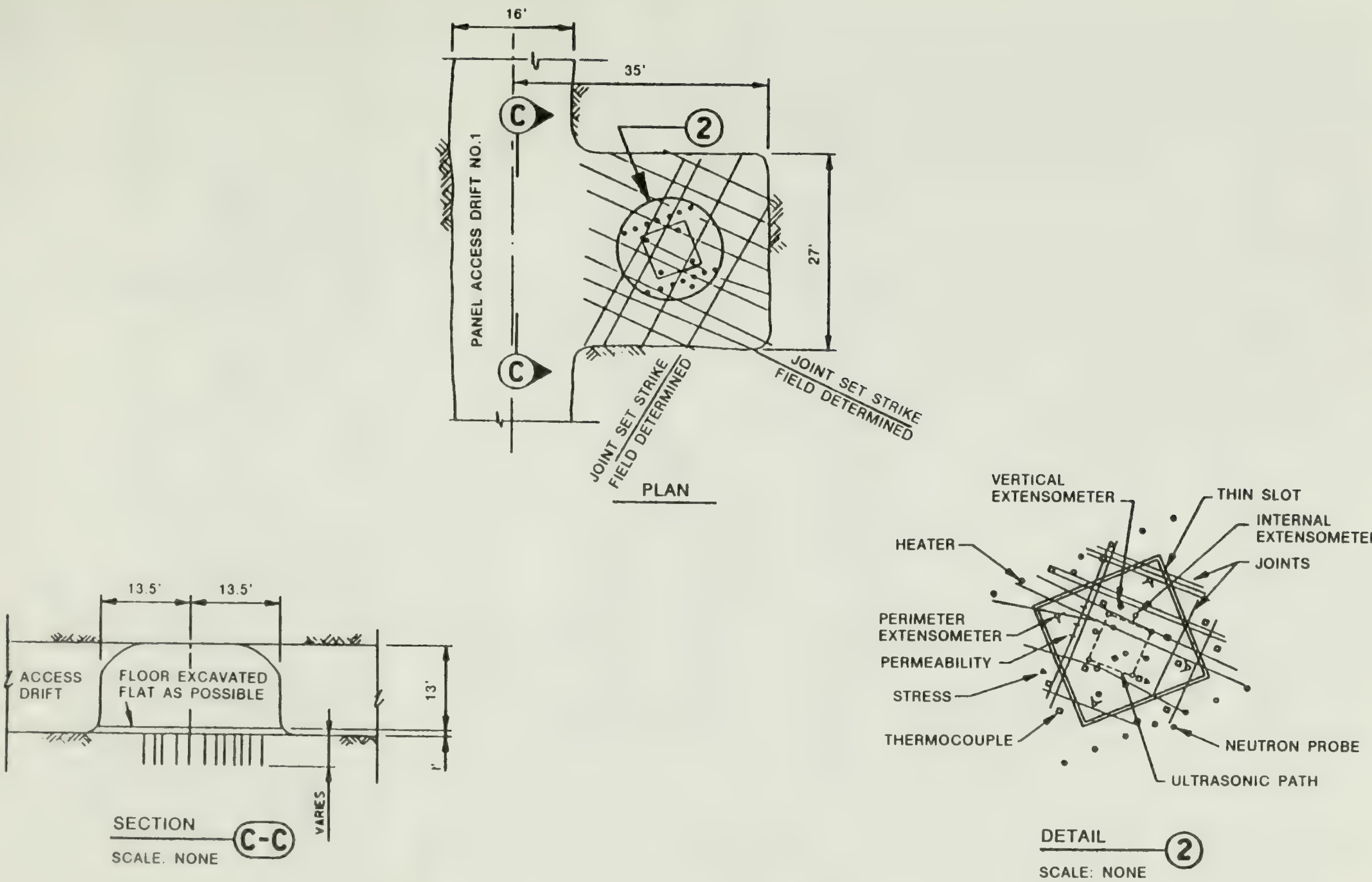



**Figure 8.4.2-12.** Design of the Yucca Mountain heated block experiment. Modified from Title I design package (DOE, 1988).

Constraints and zones of influence

Flexibility in location of the test alcove is required to ensure that the block used contains a joint spacing and orientation that is reasonably representative of the repository horizon. The experiment should be located in a low traffic area so that dust and vibrations from other construction and testing do not interfere with sensitive displacement measurements being made as the block is loaded (Zimmerman et al., 1986a).

The thermal zone (within 5°C isotherm above ambient temperature) resulting from two thermal cycles lasting a total of 100 days is calculated to extend to approximately 32.5 ft (10 m) from the center of the block (Costin and Chen, 1988). Thus, the thermal zone will extend approximately 20 ft (6 m) beyond the test alcove in a direction normal to the lines of heaters. Within the thermal zone, the 100°C isotherm will attain a maximum distance of approximately 3 ft (1 m) radially from the centerline of the heaters. Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending up to a maximum of approximately 33 ft (10 m) beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region that may extend to a maximum of approximately 36 ft (11 m) from the lines of the heaters is created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 11 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, the zones of potential chemical and hydrological alteration are approximately coincident to the zone of thermal alteration. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress. Construction of the small alcove will produce a stress-altered zone of approximately one alcove diameter, 27 ft (8.2 m) around the experiment.

<u>Activity: Thermal stress measurements (Section 8.3.1.15.1.6.4)</u>

Purpose and operations

These tests will measure thermal stresses in a relatively large volume of jointed rock and relate the stress changes to thermomechanical displacement for numerical modeling. The specific number and location of these experiments has not yet been defined. At each experiment location, single slots will be cut in both the back (roof) and rib (wall) 6 ft (2 m) long and 6 ft (2 m) deep after reference pins are established on either side. Flat-jacks will be installed in the slots, and heaters will be installed in the holes drilled on either side of the slots (Figure 8.4.2-13). An insulating blanket will be installed over the test area of the drift to reduce heat loss. Heaters will be started and stress changes in the near-field volume will be monitored as thermal loading increases.

Constraints and zones of influence

Flexibility with regard to rock conditions and the orientation of joints is one of the constraints in selecting the specific region of rock where the

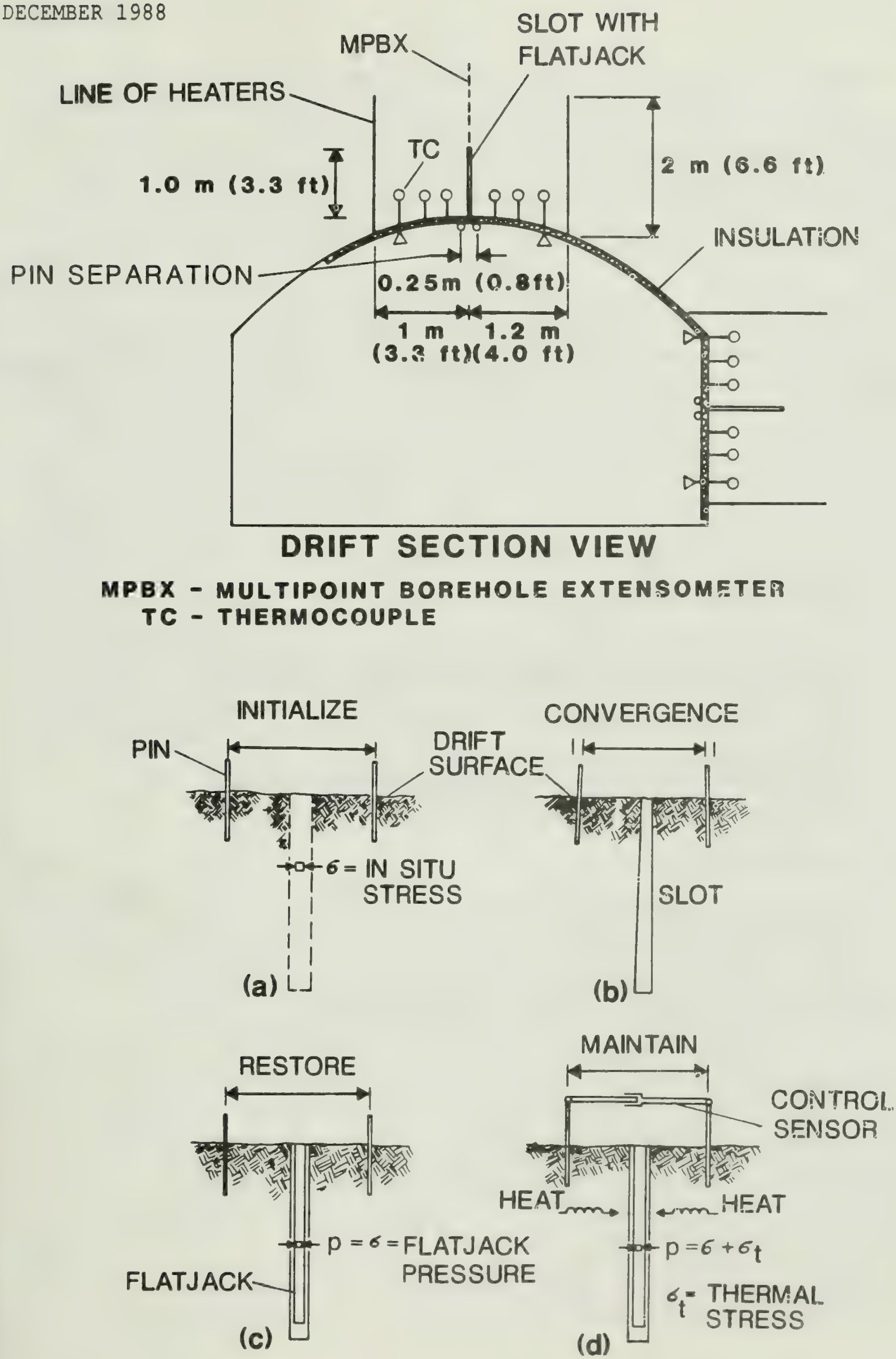



**Figure 8.4.2-13.** Conceptual design for thermal stress measurements.

test is conducted. This test cannot begin until any other measurements in the test area are completed. Because one objective of the test is to measure stress changes induced in the rock mass by thermal loading, no mining should be conducted within a two drift diameter standoff region until the test is completed, because this could affect stress measurements in the test drift. The test should be conducted in a drift that can be isolated from normal mine traffic because of the high temperatures and stresses that will be generated in the roof of the drift.

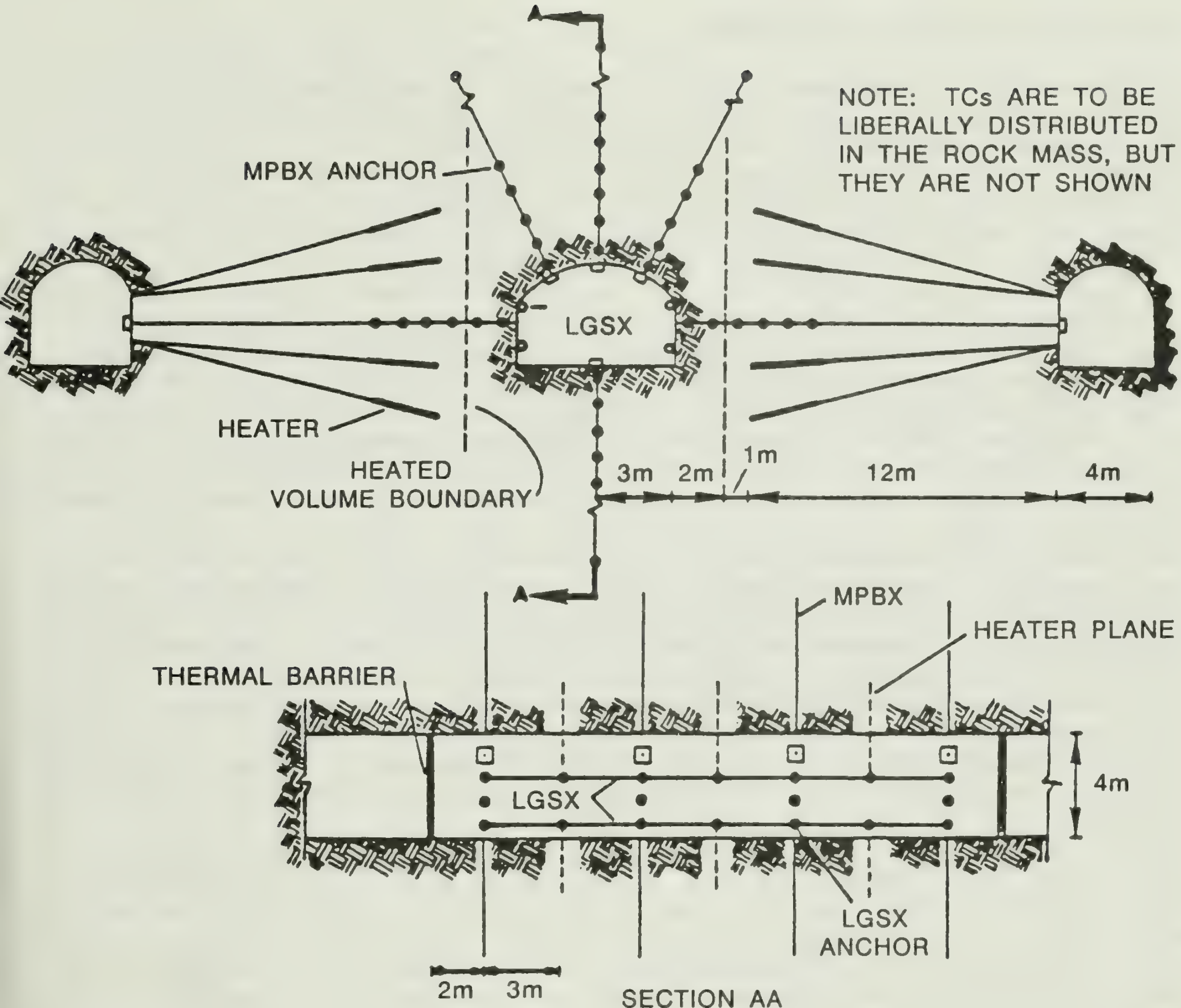
At 90 days, for the test being conducted in the roof, the +5°C isotherm (above the expected ambient temperature) will be approximately 5 m horizontally from the drift wall and approximately 7 m vertically from the roof. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress (Bauer et al., 1988). Within the 5°C isotherm, it is predicted that the 100°C isotherm will be approximately 1 m radially from the centerline of the heaters (approximately 3 m horizontally from the drift centerline). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm. Hence a zone of saturation is likely to occur in this region. The water contained in this region is anticipated to be imbibed into the matrix in a zone that may extend to approximately 10 m beyond the 100°C isotherm (Martinez, 1988). Because of the small volume of rock dehydrated, the hydrologically altered region is likely to be less than the 10 m estimated maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Stress alteration due to mining extends two drift diameters (50 ft) laterally, which is greater than any alteration expected due to the local heat load (Bauer et al., 1988).

<u>Activity: Heated room experiment (Section 8.3.1.15.1.6.5)</u>

Purpose and operations

The heated room experiment is in the early stages of design definition and is intended to measure thermomechanical responses in fractured welded tuff at a drift-size scale to acquire data for evaluating both pre- and postclosure design. Measurements will also be used to support the validation phase of both empirical and numerical design methods.

In the dedicated test area at a location to be determined, a drift representative of repository-size drifts is planned to be excavated and the rock around it heated. Either a preexisting drift will be used, or more likely, a new drift, as shown conceptually in Figure 8.4.2-14, may be constructed in the performance confirmation area specifically for this experiment. The drift will be instrumented to provide data on rock mass deformation, rib stress change, thermal conductivity, heat capacity and thermal expansion coefficient, and ground-support loading and deformation, as well as to estimate the region in which the stress state is changed by heating. The experiment may involve more than one drift opening so that temperatures around and between drifts more nearly represent those expected in the repository.




LGSX LONG GAGE SURFACE EXTENSOMETER
MPBX MULTIPLE-POINT BOREHOLE EXTENSOMETER
TC THERMOCOUPLE

**Figure 8.4.2-14.** Conceptual layout for heated room experiment.

Constraints and zones of influence

Flexibility in location and orientation of the experiment is a constraint necessary to ensure that the geologic conditions (rock quality, joint orientation, etc.) are representative of and consistent with those expected in the repository block. Because it will be approximately 2 to 3 years after heating begins before data are available, the test should begin as soon as possible. Special doors and thermal barriers may be required to control the ventilation and heat flow from the area.

Estimates of the potential zone of influence of the experiment were taken from preliminary design calculations (Bauer et al., 1988) that assumed the drifts were separated by 65 ft (20 m) center to center with the test drift being 20 ft (6.1 m) wide and the access drifts being 13 ft (4 m) wide. For a 50 kW heat load and a 3-yr test duration, the thermal zone resulting from this experiment will extend approximately 90 ft (28 m) laterally from the central drift. Although the thermal zone extends slightly above and over the access drifts, the extent of the thermal zone is effectively limited by the presence of the two access drifts. Thermally induced stresses are expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses are predicted to be less than 10 percent above the initial in situ stress (Bauer et al., 1988). The 100°C isotherm will attain a maximum distance of approximately 7 m horizontally and 10 m vertically from the center of the line of heaters on each side of the central drift (Bauer et al., 1988). Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm boundary. Hence, a zone of saturation is likely to occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone extending a maximum of approximately 33 ft (10 m) beyond the 100° C isotherm (Martinez, 1988). The heated region, however, is bounded by the two access drifts, which are ventilated. Thus, the region of potential hydrologic alteration will likely not extend beyond the access drifts. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, both the zones of potential chemical and hydrological alteration are expected to be contained within the zone of thermal alteration. The stress-altered region resulting from the mining of the drifts will extend laterally approximately 100 ft (31 m) from the centerline of the central experiment drift (i.e., out to two drift diameters from the outside access drifts) and 20 ft (6.1 m) (one drift diameter) from the end of the central drift. Possible changes in orientation were not considered. If the experiment continues longer than 40 months, additional standoff distance may be required. The layout should provide standoff distances of 150 ft (45 m) laterally from the centerline of the central drift and 50 ft (15 m) longitudinally from the end of the central drift.

Activity 4.4.6: Development and demonstration of required equipment (Section 8.3.2.5.6)

Purpose and operations

The purpose of this activity is to drill, line, and instrument (for convergence monitoring) two waste emplacement-size holes to evaluate the horizontal boring technology and equipment performance in the Topopah Spring welded unit.

A development prototype boring machine (DPBM) has been designed for demonstration in underground testing. The DPBM would be capable of drilling and installing a metal lining in long, horizontal boreholes. Tests currently under consideration in the ESF involve the drilling and lining of two 250-ft (76.2-m) long horizontal holes in the dedicated test area and/or the upper DBR. The drilling of these holes will be highly instrumented so that data on drill performance can be obtained for use in predicting drill performance in the repository. Substantial uncertainty exists about whether this test will be conducted. The uncertainty is because the DPBM will be developed only if the long, horizontal borehole concept is selected as the preferred option for waste emplacement. Ongoing engineering studies are evaluating the relative advantages of both the vertical emplacement option and numerous horizontal emplacement options. The test may also evaluate the proposed liner emplacement technique. Because of the possibility that the test may be canceled, no specific area has been set aside in the current design for this testing.

Constraints and zones of influence

The prototype boring machine has been designed to excavate long holes for waste emplacement. The process of boring will not use water. Thus, the principal constraints on the ESF design resulting from this test are the requirements to provide adequate area and utilities (electric power and compressed air) if the test is conducted. Dust and noise must also be carefully controlled. Because of the dry excavation method used in the test, no significant hydrological or geochemical alteration is expected from the excavation. The stress-altered region that will result from the excavation is estimated to be approximately two borehole diameters from the liner.

<u>Activity: Plate loading tests (Section 8.3.1.15.1.7.1)</u>

Purpose and operations

Plate-loading experiments, as illustrated in Figure 8.4.2-15, will be performed at selected locations in the upper DBR, MTL DBR, and in other locations on the main test level to measure the rock-mass deformation modulus and evaluate the fracture zone adjacent to the mined openings. Rock deformations will be measured with a multipoint borehole extensometer oriented parallel to the load axis in the center of the plate area. Deformation of the loading column will be monitored with rod extensometers. Values of the rock deformation moduli will be calculated by using the rock-deformation and the applied stresses. Moduli from different stations will be compared to evaluate spatial variability within unit TSw2 (low lithophysal Topopah Spring). These data primarily will be applicable to the material around an opening that has been affected by the presence of the opening and by the excavation process. As such, the moduli will represent lower bounds on the modulus of the undistributed rock mass.

Constraints and zones of influence

This test will be conducted at several locations to help evaluate values of rock-mass modulus of deformation. Because the test is short (approximately 2 weeks at each location) and stresses only a small amount of rock (approximately 1 $m^3$), no special constraints are specified other than ensuring that the tests are not conducted in regions altered by other testing. No

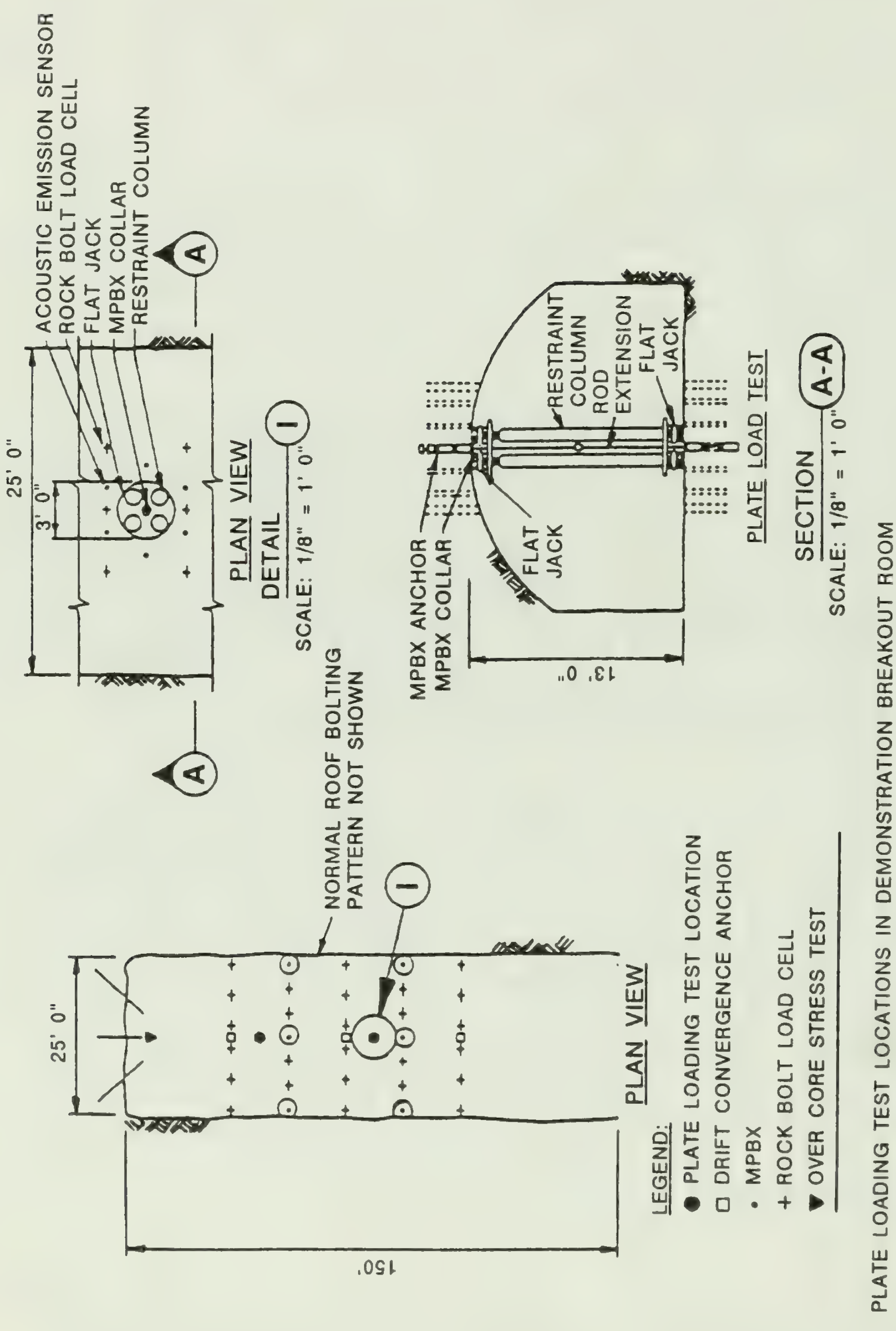



Figure 8.4.2-15. Design of the plate loading test.

permanent alteration to the local hydrological, chemical, or thermal conditions will result from this test.

Activity: Rock-mass strength experiment (Section 8.3.1.15.1.7.2)

Purpose and operations

The objective of this activity is to evaluate the mechanical behavior of the rock mass or its components. Experiments will be performed to obtain information with regards to the mechanical response of single joints and multiply jointed volumes of rock. It is envisaged that this experiment will be conducted in several areas that are representative of the range of conditions encountered in the exploratory shaft facility (ESF). The information will be used to evaluate potential scale effects between laboratory and in situ conditions, to provide data to evaluate empirical design criteria, and to provide data to evaluate and validate jointed-rock models.

Experiments will be conducted in several areas on the main test level chosen to be representative of the geologic conditions expected in most of the repository. The experiments will be conducted in stages. The joint shear-strength stage will be performed on samples of field-scale size, where field-scale is considered the expected in situ joint length (up to a few meters is possible). If random jointing is encountered, then the compressive strength stage of the experiment will be performed in which a volume of randomly jointed rock will be loaded to a point beyond its maximum support capacity. The final stage of this experiment will require a block of jointed rock (1 to 3 $m^3$) to be carefully characterized as to joint spacing, aperture, properties, etc., and then loaded to predetermined stress levels. This stage of the experiment will provide information on joint loading and closure characteristics for evaluating and validating a jointed-rock model.

Constraints and zones of influence

This test can be conducted in any drift on the main test level where suitable rock conditions exist. Thus, no special constraints exist other than ensuring that the tests are not conducted in regions that have been altered by other testing. The location of the test will be determined after the drifts in the dedicated test area are mined.

The experiment will be similar to the plate loading test in that only a small region of rock (approximately 1 to 3 $m^3$) will be directly loaded and the effects of the loading will likely extend only a distance of a few times the width of the area over which the load is applied. No permanent alteration to the local hydrological, chemical, or thermal conditions will result from this test. No significant zone of influence will result from the rock-mass loading imposed in this activity.

Activity: Evaluation of mining methods (Section 8.3.1.15.1.8.1)

Purpose and operations

These tests will monitor and evaluate mining methods for shaft and drift openings, with emphasis on rock responses in a variety of lithologic and structural settings that may be encountered in the long exploratory drifts.

This activity will be to develop recommendations for mining in the repository. Mining methods in ES-1 and in the long exploratory drifts will be monitored. Mining investigations will be concentrated in the widened (repository-size) portions of the long drifts and will include particle velocity measurements, segmented blasting of rounds, and examination of blast-induced damage in boreholes.

Constraints and zones of influence

This activity is primarily observational and will be conducted in the long exploratory drifts and ES-1 where a variety of geologic conditions are expected. Because the activity is primarily observational, no special constraints are required to include it in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from it.

Activity: Evaluation of ground-support systems (SCP Section 8.3.1.15.1.8.2)

Purpose and operations

The purpose of this activity is to develop recommendations for a ground-support methodology to be used in drifts in the repository, based on evaluations of the ground-support techniques used in the underground excavations, and on experimentation with other ground-support configurations. This activity will be carried out on the main test level. The selection, installation, and performance of the support systems used will be monitored. Experimentation with ground supports will include pull tests on rock bolts, observation of unsupported rock, strength measurements on shotcrete cores, and trials of alternate ground-support configurations from those prescribed for the ESF. The effects of heat on ground support will be considered in the heated room experiment.

Constraints and zones of influence

These activities will be conducted in the main test level where a variety of geologic conditions are expected. Because this activity is observational, no special constraints are required to include it in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity other than that created by excavating the opening.

Activity: Monitoring drift stability (Section 8.3.1.15.1.8.3)

Purpose and operations

The purpose of these tests is to monitor drift convergence throughout the ESF to understand potential instabilities and provide data for empirical evaluations. This activity involves monitoring drift convergences and drift maintenance activities around the main test level. Instrumentation will be concentrated in the long drifts, although convergence measurement stations may be set up anywhere in the main test level drifts. In the long drifts, convergence measurements will be taken in a continuous manner, if practical. Rock-mass relaxation will be investigated in the repository-scale portions of the long drifts using multiple-point borehole extensometers. Rock falls and

maintenance activities will be documented through observations and with photographs.

Constraints and zones of influence

This activity will be conducted in the main test level where a variety of geologic conditions are expected. Because this activity is observational, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity (i.e., no significant zone of influence).

Activity: Air quality and ventilation experiment (Section 8.3.1.15.1.8.4)

Purpose and operations

The purpose of these tests is to assess the impact of site characteristics on ventilation requirements to ensure a safe working environment. This activity consists of (1) measurements of radon emanation; (2) surveys of air-flow and pressure, temperature, and humidity; (3) determinations of air resistance factors; and (4) dust characterization. The radon emanation measurements will be made in a dead-end drift that has been sealed with a bulkhead at equilibrium conditions and at various rates of airflow. Radon concentrations might also be measured in a borehole. Activities 8.3.1.15.1.8.1 through 8.3.1.15.1.8.3 (discussed earlier) will be performed with portable instruments over periods of a few days each. They are not expected to interfere significantly with other underground activities.

Constraints and zones of influence

This experiment will measure the rate of radon emanation from the TSw2 formation and will be conducted on the main test level. Because this requires only periodic air sampling, no special constraints are required to include this activity in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity.

Activity: In situ testing of seal components (Section 8.3.3.2.3)

Purpose and operations

As described in more detail in Section 8.3.3.2.2.3, additional evaluations will be required before defining appropriate field tests for seal components. The most important needs will be the characterization of the repository environment and results of laboratory studies on seal material properties. Specifically, the occurrence or non-occurrence of water at the repository horizon will be essential to define an appropriate seal test. Much of the information will be obtained from other testing (primarily hydrologic) programs conducted in the ESF. Some laboratory testing can also aid in developing the details of a field test, for example, (1) laboratory or bench-scale testing to determine the rate of movement of fines into fractures as a function of flow volume and (2) laboratory testing to determine index properties for the emplacement of grout, earthen, or cementitious materials.

Once this and other additional information is obtained, the need for the following categories of field tests will be evaluated:

1. Verification of emplacement techniques.

2. Saturation or infiltration tests, including the effects of fines on drainage potential.

3. Seal behavior under in situ hydrogeological conditions.

The methodology for selecting needed in situ seals tests is given in Section 8.3.3.2.2.3.

Constraints and zones of influence

While particular experiments are not defined yet, the three general categories of field-test operations are expected to provide some constraints on the test location. For example, if testing is performed to verify emplacement techniques, this operation may involve a significant amount of equipment, as well as construction operations that may require physical separation from other more sensitive tests.

The mechanical zone of influence from sealing tests is likely to be within the zone created as a result of the related excavation. Initial tests would most likely be done without heating so that no thermal zone of influence is expected. Hydrologic considerations may, however, be significant. If testing of sealing systems is needed under simulated flooding scenarios, then a significant amount of water may be required. If this is required, then a hydrologic zone of influence may result. If this zone of influence were to become unacceptably large or the test were to significantly increase uncertainties relative to postclosure performance, an alternative test could possibly be conducted either in the laboratory or in an alternate field location removed from the ESF. The geochemically altered zone would depend on the types of materials tested and upon the total amount of water used in each test. When these tests are defined, test and associated constraints and performance related impacts will be described in semiannual progress reports.

Activity: Overcore stress experiments in the exploratory shaft facility (Section 8.3.1.15.2.1.2)

Purpose and operations

The overcore stress experiments will be performed to determine the in situ state of stress above and within the repository horizon, to determine the extent of excavation-induced stress changes, and to relate stress parameters to rock-mass heterogeneities.

Soon after access is available at the upper DBR and later, at the MTL-DBR, small-diameter holes will be drilled to prescribed orientations and lengths (longer than three shaft or drift diameters). A stress sensor will then be installed, and the instrumented center hole will be overcored in stages. Stress data will be taken as the instrumentation of each stage is overcored.

Constraints and zones of influence

Flexibility in location of the tests within the upper and lower DBRs is required because intact segments of core are required. Thus, the location, distribution, orientation, and apertures of fractures need to be examined before tests are conducted. No mining, testing, or construction should take place in such a way as to influence the in situ stresses at the bottom of the test holes. Test holes should not be drilled near other instrument holes. Tests will be conducted within the approximately 50-ft-long boreholes extending downward and horizontally from the end of the DBR. Small volumes (approximately 1 to 2 gal) of water may be injected in the vertical test holes at the bottom of the shaft for low-volume hydraulic fracture stress tests. If the quantities of fluid used are carefully limited, the small water volume used is not be expected to move beyond the volume of rock that will be mined as the shaft is extended. Thus, this activity is not expected to result in significant hydrological, chemical, or thermal disturbance to the rock mass.

Activity: Matrix hydrologic properties testing (Section 8.3.1.2.2.3.1)

Purpose and operations

The purpose of the matrix hydrologic properties tests is to develop a comprehensive data base on matrix flux properties in the unsaturated-zone tuffs at Yucca Mountain. This activity includes collecting bulk and core samples, taken after selected blasting rounds during ES-1 and drift construction and from core holes. The collected samples will be packaged, labeled, and sent to a laboratory for analyses as described in Section 8.3.1.2.2.3.

Constraints and zones of influence

Rock-matrix hydraulic properties of large rock samples taken from selected horizons of ES-1 during construction will be measured. Because of the nature (sample collection) and location of the test, no special constraint beyond the planned control and tagging of construction water will be imposed on the layout or operation of the ESF, and no additional perturbation to the natural conditions will result from this activity.

Activity: Intact-fracture test in the exploratory shaft facility (Section 8.3.1.2.2.4.1)

Purpose and operations

The intact-fracture test will be used to evaluate fluid-flow and chemical transport properties and mechanisms in relatively undisturbed and variably stressed fractures to enhance understanding of physics of flow and for flow modeling.

Fracture-sampling locations will be selected at each breakout horizon (upper DBR and main test level) on the basis of detailed fracture maps. At about 12 locations (to be determined), a small pilot hole will be drilled across a fracture, a rock bolt anchor will be installed, the pilot hole will be overcored, and the sample will be withdrawn (Figure 8.4.2-16). The sample

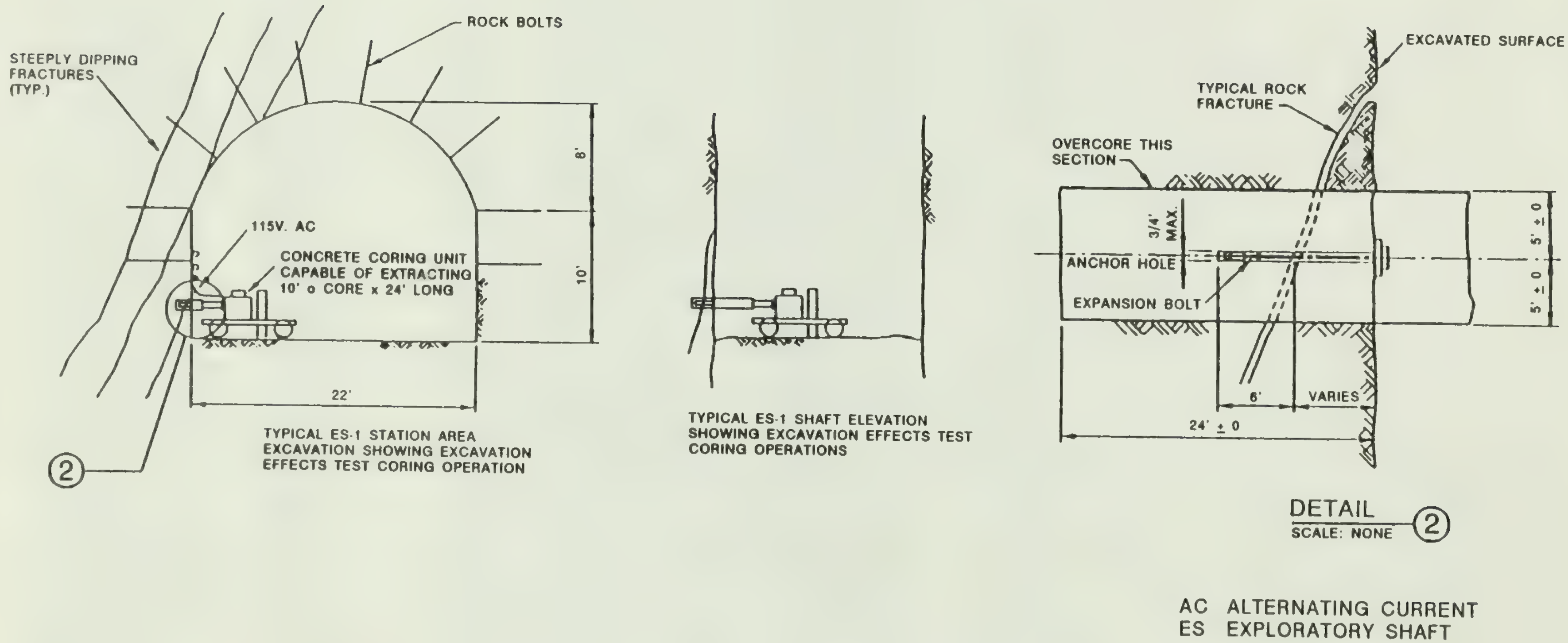



**Figure 8.4.2-16.** Intact fracture test arrangement - typical. Modified from Title I design package (DOE, 1988).

will be packaged, labeled, and transported to an onsite field laboratory for intact-fracture analyses as described in Section 8.3.1.2.2.4.1.

Constraints and zones of influence

Flexibility in sampling location is required to locate suitable fractures. Because only sample collection will be conducted in the ESF, no other special constraints on the layout are required. No hydrological, chemical, or thermal disturbance is expected from this activity.

Activity: Percolation tests in the exploratory shaft facility (Section 8.3.1.2.2.4.2)

Purpose and operations

This test will be used to observe and measure fluid flow through a network of fractures under controlled in situ conditions in order to characterize and quantify important flow processes in fractured welded tuff. The percolation test design is not completely finalized. The test is planned to use a large, isolated block of rock 6 ft (2 m) on a side. The block will be instrumented to detect fluid flow under physical conditions that can be mechanically controlled and systematically varied. Tracer-tagged water will be introduced from a trickle system/sand bed on the surface of the block.

Constraints and zones of influence

Flexibility in location of the block excavation is required because of the need to have a high fracture density spacing in the block. Orientation is not considered critical. Mining disturbances should be limited so that the rock mass is not excessively damaged during excavation and preparation. Hence, the zone of hydrologic or geochemical influence will not extend beyond the isolated test block. Stress redistribution around the experiment drift will extend approximately two drift diameters from the drift boundaries.

Activity: Bulk-permeability test in the exploratory shaft facility (Section 8.3.1.2.2.4.3)

Purpose and operations

The purpose of the bulk-permeability test activity is to assess the fluid transport properties in relatively large volumes of minimally disturbed Topopah Spring welded tuff. Tests are planned at four separate locations in the main test level, selected on the basis of detailed fracture maps. At each location, a small-diameter hole 100 to 200 ft (30 to 60 m) deep, will be air-cored and logged. Air permeability will then be measured in packed-off intervals. If the rock is deemed suitable for the test based on the preliminary results, three additional holes subparallel (frustrum configuration) to the first, will be air-cored, logged, and instrumented.

Cross-hole air permeability (injection) tests will be conducted in the formation. Pressure, temperature, and humidity sensors will be installed in experiment boreholes. Selected holes will then be pressurized, and the air

movement outward to sensors in the other holes will be monitored. The measurements will be repeated as required by using positive or negative pressures in the boreholes.

Constraints and zones of influence

Constraints relative to flexibility of location and orientation are required because fracture geometry and orientation relative to the test holes are important. Test areas must be outside the hydrologic zones of influence of other tests or mining activities. The feasibility of and possible need for nearly "dry" mining in the vicinity of this test are being investigated.

Test holes for each test will be dry-drilled deep enough (approximately 150 ft (46 m)) into the rock mass so that the cross-hole permeabilities will be measured in undisturbed rock (outside the stress-altered zone of the excavations). Gas-phase pressure pulses may occur as much as 100 ft (30 m) away from centerline of the cross-hole frustum configuration. Test holes may penetrate the rock mass to 150 ft (46 m). Thus, a zone of influence extends along the four hole frustum out to 150 ft (46 m) longitudinally and radially to approximately 100 ft. The air injected for this test will contain a tracer to allow discrimination between the natural gas in pore spaces and the injected air. Hence no interference caused by air injection between this test and any other test is expected. No significant mechanical, hydrological, thermal, or chemical alteration to the rock mass is expected to result from this activity, that is, there is no zone of influence.

Activity: Radial borehole tests in the exploratory shaft facility (Section 8.3.1.2.2.4.4)

Purpose and operations

The radial borehole tests will investigate vertical and lateral movement of gas, water, and vapor on and across hydrogeologic contacts and within the Topopah Spring unit, and evaluate near-field excavation effects on hydrologic properties.

Eight depths have been tentatively chosen as sites for drilling the radial boreholes. At each depth location, two 4- to 8-in. (10.2- to 20.3-cm) diameter, 30-ft (9.1-m) long coreholes will be drilled using air as the drilling fluid. Orientation of the radial boreholes at each depth location will be determined by analyzing fracture data collected during shaft wall mapping (see Activity 8.3.1.4.2.2.4 for mapping details). Core will be collected, packaged, labeled, and transported to an onsite laboratory for hydrologic analyses (fracture and matrix properties). The holes will be logged and surveyed for fracture and moisture data. Nitrogen injection tests in packed-off intervals will be conducted to obtain gas permeability data. Across stratigraphic contacts, crosshole permeability tests will be run with both gas and water. Short-term monitoring for moisture resulting from shaft mining will be done periodically when mining resumes. Long-term monitoring of matrix water potential, pressure, and temperature will also be conducted; formation gases will be sampled periodically.

Constraints and zones of influence

The radial boreholes will be drilled deep enough to be beyond the expected zone of mechanical and hydrologic influence of the shaft. The holes will be used to monitor the movement of construction water from the shaft in order to measure the hydrologic zone of influence resulting from shaft construction. These monitoring activities require no special constraints, nor do they alter the hydrologic or geochemical state of the rock mass. However, at the stratigraphic contacts between the Tiva Canyon welded unit and the Paintbrush non-welded unit and between the Paintbrush non-welded unit and the Topopah Spring welded unit, crosshole permeability tests will be run with both gas and water. The water injected under low pressure is estimated to influence a zone extending 10 m from the test location (Martinez, 1988). Further, the hydrologic zone of influence is expected to be localized in a vertical sense near the top 10 m of the Topopah Spring welded unit. The calculations of Peters (1988) indicate that the vertical movement of the test water will be very slow and will not be expected to cause significant disturbance at the main ESF test level. Geochemical effects are not expected to extend beyond the zone of influence resulting from water movement. The air injected for this test will contain a tracer to allow discrimination between the natural gas in pore spaces and the injected air. Since a portion of the hydrochemistry testing is expected to be performed at the same location as the radial borehole test, the use of an air tracer will control the potential interference between these tests. No thermal or mechanical alterations to the rock mass will result from this test.

Activity: Excavation effects test in the exploratory shaft facility (Section 8.3.1.2.2.4.5)

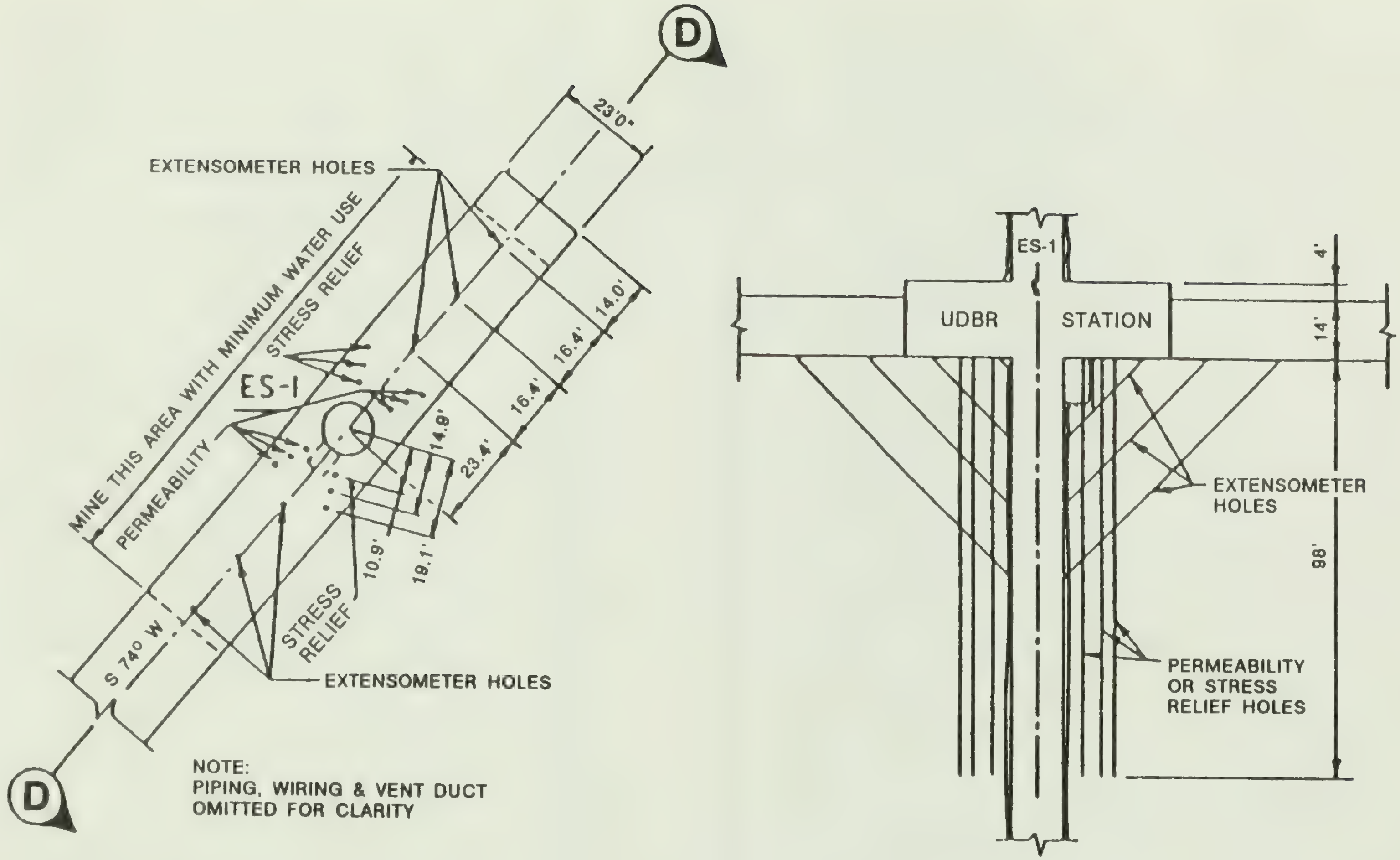
Purpose and operations

The excavation effects tests will measure stress changes in the near-field wall-rock as the shaft is mined and lined, and measure air-permeability changes that result from the stress redistribution.

Tests are planned at the upper DBR and at the main test level in ES-1. At each level multiple small-diameter holes will be drilled parallel or subparallel to the unexcavated shaft wall but set back selected distances from it (Figure 8.4.2-17). All holes are planned to be air drilled/cored, logged, and surveyed; some of the holes will be instrumented to monitor stress changes and some to monitor permeability changes as the shaft is advanced. Stress and permeability data will be taken in drillholes extended below the bottom of the shaft from the upper DBR. Long-term permeability measurements will be made and temperature and moisture data collected. Additional holes may be drilled to handle the instrumentation packages if they are determined to be necessary during prototype testing.

Constraints and zones of influence

Flexibility is the only significant constraint identified for this test. It is required for locating drill holes for tests at the upper DBR and at the main test level. The instrument holes will be drilled from the DBR at distances up to 49 ft from the shaft. They will extend as much as 100 ft below




PLAN - UDBR
SCALE: 1" = 25'

SECTION D-D
SCALE: 1" = 25'

ES EXPLORATORY SHAFT
UDBR UPPER DEMONSTRATION BREAKOUT ROOM

**Figure 8.4.2-17.** Typical excavation effects test. Modified from Title I design package (DOE, 1988).

each breakout creating a zone of potential mechanical interference. No thermal, chemical, or hydrological alteration of the rock mass is expected as a result of this activity.

Activity: Perched-water test in the exploratory shaft facility (Section 8.3.1.2.2.4.7) (Contingency test)

Purpose and operations

The purpose of the perched-water test is to detect the occurrence, and delineate the lateral and vertical extent, of perched-water zones (if encountered) during shaft excavation, to identify perching mechanism(s), and to sample the water for chemical analyses. Because there is significant uncertainty regarding the likelihood of encountering perched water, the perched-water test is categorized as a "contingency test."

If perched water is encountered while mining ES-1, one or more small-diameter hole(s) will be drilled to enhance drainage, facilitate collection of water samples, and allow flow and/or pressure measurements to be made. The hole(s) will also be instrumented and sealed during testing to obtain data on hydraulic pressure and water potential over time. The recent addition of the multipurpose boreholes in close proximity to both ES-1 and ES-2 should provide insight into whether or not perched water is present at those locations and may provide data to support the finalization of the test plans.

Constraints and zones of influence

This test will be conducted only if perched-water zones are encountered during construction of ES-1 or ES-2. If perched water is encountered, boreholes will be drilled from the shaft(s) for testing and sampling. Because of its nature and location, no special constraints on the layout or operation of the ESF are imposed by this experiment.

Because this activity only involves sampling and drilling of small-diameter holes only, no mechanical, chemical or thermal alteration of the rock mass is expected.

Activity: Hydrochemistry tests in the exploratory shaft facility (Section 8.3.1.3.3.4.8)

Purpose and operations

The hydrochemistry tests will determine the chemical composition, reactive mechanisms, and age of water and gas in pores, fractures, and perched-water zones within the unsaturated tuffs accessible from the ESF and/or affiliated core holes.

During shaft-sinking at selected locations, large block (>6 in. (16 cm) diameter if possible) samples will be collected from the blast rubble, packaged, labeled, and transported to a surface laboratory for analysis of pore and fracture-fluid chemistry. Core from selected shaft, drift, and test alcove drillholes will also be collected and analyzed as described in Section 8.3.1.2.2.4.8.

Constraints and zones of influence

Bulk-rock samples taken from ES-1 at various depths during construction are required for this experiment. Because sample collection is the only activity taking place in the ESF related to this experiment, no special constraints on the layout or operation of the ESF are imposed by this experiment, and no additional perturbation to the natural conditions is expected to result from this activity. The methods developed during prototype testing to control both construction blasting and water use (including tracer tagging) are expected to be sufficient to ensure that the geochemical analysis conducted under this activity will not be adversely affected by construction operations. Studies are in progress to assess the effect of by-products of blasting materials and the tracer-tagged water on the type of geochemical analysis proposed for this test. One of the results of this effort will be to define the construction controls to be used in the ESF needed to successfully complete this test.

Study: Diffusion tests in the exploratory shaft facility (Section 8.3.1.2.2.5)

Purpose and operations

The purpose of these tests is to determine in situ diffusivity coefficients for nonsorbing ions in the Topopah Spring welded tuff. At four locations to be selected on the main test level, small-diameter holes will be air-drilled to a vertical (or horizontal) depth of 33 ft (10 m), a suitable nonsorbing tracer will be deposited at the bottom in a packed-off zone, then the holes will be capped and left undisturbed for periods of 3 to 12 months. Finally, the test intervals will be overcored, and the core will be removed to a laboratory for analysis of tracer diffusivity.

Constraints and zones of influence

Flexibility in experiment locations is a necessary constraint. Excessively fractured rock should be avoided. The test will be conducted at the end of the approximately 33 ft (10 m) vertical or horizontal boreholes. The region around the end of the boreholes must not be affected by stress changes due to mining or other construction or by alterations in the in situ water saturation.

The mechanical zone of influence is expected to extend about 33 ft (10 m) beyond or below the alcove due to test hole drilling. The lateral extent of influence around the test holes is approximately 0.3 ft (at the end of the boreholes) which is estimated from the extent of movement of the tracer species placed in the borehcle. This estimate was taken from previous field work using a similar technique (Birgersson and Neretnieks, 1982). No thermal or hydrological effects are expected from this test.

Activity: Chloride and chlorine-36 measurements of percolation at Yucca Mountain (Section 8.3.1.2.2.2.1)

Purpose and operations

These measurements will be made at various depths to determine the rate of water movement downward through the unsaturated-zone tuffs using the chlorine-36/chloride concentration ratio. As the ES-1 shaft is being excavated, large bulk samples (from up to 30 locations) will be periodically collected, packaged, and labeled for laboratory analysis as described in Section 8.3.1.2.2.2.1. Because of the requirement to extract pore water to conduct the chlorine-36 test, several hundred pounds of rubble may be needed at each sampling location.

Constraints and zones of influence

Rock samples from ES-1 will be collected at several depths for laboratory analysis under this activity. Because only samples are collected in ES-1, no special constraints on the layout or operation of the ESF are imposed by this experiment. The methods developed to control both the construction blasting and use of water (including tracer tagging) are expected to be sufficient to ensure that the geochemical analysis conducted under this activity will not be adversely affected by construction operations. Studies are in progress to assess the effect of explosion by-products and the tracer-tagged water on the type of geochemical analysis proposed for this test. One of the results of this effort will be to define the construction controls to be used in the ESF that will allow these tests to be successfully completed.

Study: Engineered barrier system field tests (Section 8.3.4.2.4.4)

Purpose and operations

The engineered barrier system field tests will determine the in situ hydrologic transport properties in rock at the repository horizon and determine the effect on water chemistry of near-field thermal perturbation. These waste package environment tests will provide thermal, hydrologic, mechanical, and limited chemical alteration information during an abbreviated thermal cycle (of at least 1 year duration) in the very near-field emplacement environment. In test alcoves in the dedicated test area, horizontal and vertical heater emplacement holes and small-diameter parallel and perpendicular instrumentation holes will be typically drilled as shown in Figure 8.4.2-18. Heater canisters and associated instrumentation packages will be inserted to monitor thermal, moisture, and stress and strain parameters during a thermal cycle (heating and subsequent cooling) in each test. In selected tests, water will be injected during heating and cooling stages while monitoring takes place. Core from the rock mass adjacent to the heater hole will be recovered and petrologic, petrographic, mineralogic, and related laboratory analyses will be performed to identify thermally induced alterations.

Constraints and zones of influence

Isolation from mining operations and mine traffic is an essential constraint for this set of experiments. Isolation from mining is required to ensure that the stress state near the heater boreholes is not influenced by

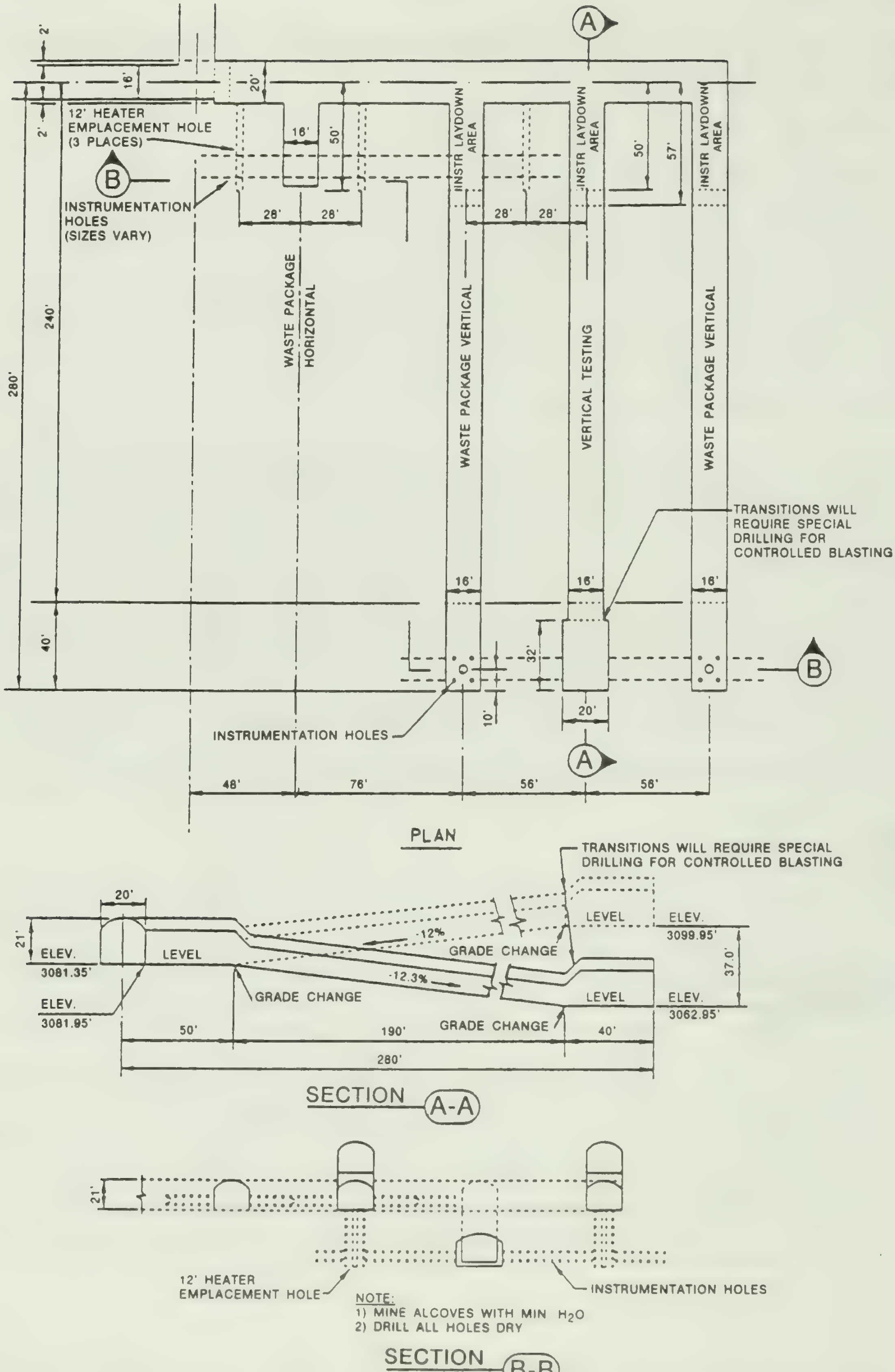



**Figure 8.4.2-18.** Repository horizon near-field hydrologic properties (waste package environment) typical test arrangement. Modified from Title I design package (DOE, 1988).

excavation of other drifts once the test has begun. Also, the experiment drifts for this area cannot tolerate significant drying of the rock mass or temperature changes from sources other than the experiment heaters. A 40 ft (12 m) standoff around the heater holes is required to allow for monitoring of condensation from the heaters. Some flexibility of orientation of the experiment drifts is desired to ensure that fracture or joint sets are not parallel to the axis of the horizontal boreholes. Recent evaluations have indicated that drift separation of approximately 75 ft may be needed to ensure isolation of the individual tests.

At 24 months, the zone of thermally disturbed rock around either vertical or horizontal heater holes is calculated to extend approximately 10 m (33 ft) radially from the heater centerline (based on the expectation of 6 months of heating at maximum power, 6 months of rampdown from the maximum power level to zero, and 12 months with no heat (Buscheck and Nitao, 1988)). Within the thermally altered zone, the 100°C isotherm will be a maximum of approximately 2 m radially from the centerline of the heater. Water within this isotherm is expected to be vaporized and to condense near the 100°C isotherm boundary. Hence, a zone of saturation may occur in this region. The water contained in this region is expected to be imbibed into the matrix in a zone that may extend to a maximum of about 10 m beyond the 100°C isotherm (Martinez, 1988). Thus, a hydrologically altered region that may extend to a maximum of 12 m from the heater is created. Because of the small volume of rock dehydrated, the hydrologically altered zone is likely to be less than the estimated 12 m maximum. Thermochemical alteration of the tuff may occur within the hydrologically altered region (Delany, 1985). Therefore, the zones of potential chemical and hydrological alteration are approximately coincident with the zone of thermal alteration. Thermally induced stresses are also expected within the thermal zone. In the rock mass beyond the maximum extent of the thermal zone, stresses should not be more than 10 percent above the initial in situ stress (Butkovich and Yow, 1986). The stress-altered region, due to mining of the test rooms, will extend two drift diameters from the outer drifts. The thermal, chemical, and hydrologic zones of influence are anticipated to be contained well within the mechanical zone resulting from drift construction.

Activity: Laboratory tests (thermal and mechanical) using samples obtained from the exploratory shaft facility (Activity 8.3.1.15.1)

Purpose and operations

The laboratory geoengineering properties tests will provide bulk, thermal, and mechanical properties data for evaluations of opening stability and related design and performance studies and/or modeling. Data from the laboratory tests will also support analyses of the geomechanical and thermomechanical field tests planned in the ESF. The ESF activities are basically the collection, packaging, and labeling of the selected bulk samples taken from the shafts or drifts. The laboratory test activities are described individually in Section 8.3.1.15.1.

Constraints and zones of influence

This activity involves collection of rock and core samples from the ES-1 main test level for use in laboratory testing. Because only sample collection is to take place in the ESF, no special constraints are imposed by this activity, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from this activity.

Activity: Hydrological properties of major faults encountered in the main test level of the exploratory shaft facility (Activity 8.3.1.2.2.4.10)

Purpose and operations

This activity is designed to provide hydrologic information in parallel with a portion of Activity 8.3.1.4.2.2.4, geologic mapping of the exploratory shafts and drifts. All faults encountered in the long exploratory drifts on the main test level will be characterized geologically under the geologic mapping activity. Hydraulic properties of the major faults encountered on the main test level will be determined by this activity. The major faults or fault zones expected to be tested are the Ghost Dance fault, a suspected fault in Drill Hole Wash, and the imbricate fault zone.

Based on major fault identification determined by the geologic mapping activity, a hydrologic testing program will be implemented. This program will consist primarily of tests conducted in boreholes drilled from drifts constructed through the fault zones and tests on core collected from the boreholes. All boreholes will be drilled using air to minimize changes in ambient moisture conditions. Onsite core examination will be conducted for preliminary determinations of fracture frequency, orientation, location and characteristics. This information will be used in conjunction with geophysical and television camera logs to select test intervals. In selected test intervals, air permeability tests will be conducted between boreholes. Other sets of boreholes will be used for cross-hole water-injection tests. All water will be tagged with a tracer. In addition, some boreholes will be instrumented to determine in situ conditions of the rock mass and monitored to determine any changes with time in these conditions. Core recovered from the boreholes will be tested to provide a water-content profile across the fault zone. This profile may provide information relative to any recent moisture occurrence in the fault zone.

Constraints and zones of influence

Constraints related to the drilling method used near the test area and the location of test holes have been identified. Both exploration and test holes must be dry cored through the fault zone. Some flexibility in the location of the holes is required so that the portion of the hole that intersects the fault zone will be far enough from the drift wall to preclude interference from drift construction (two drift diameters minimum). The exact number of holes to be drilled and their location cannot be determined before construction of the drift through the fault zone.

Instrumented drillholes may extend more than 50 ft (15.4 m) beyond the perimeter of the drift. Because the details of this activity are still being planned, the volumes of air or water to be injected into the fault region

have not yet been determined. The injected air or water is expected to be confined to the fault and not to permeate the surrounding region of more competent rock because of the greater permeability in the fault zone. No estimates of the potential travel distances along the faults for injected fluids have been made on which to base a zone of influence, but the potential impacts and zones of influence of fluid injection will be assessed before testing. Because the testing will be done only in the extremities of the long exploratory drifts, this activity is not expected to interfere with tests being conducted in the dedicated test area.

Activity: Multipurpose borehole testing near the exploratory shafts (Activity 8.3.1.2.2.4.9)

The following summary descriptions of the multipurpose borehole (MPBH) tests are provided here with the ESF testing because of the potential interrelationship between the MPBH and the ESF activities. In actuality, the MPBH is a surface-based test that would be conducted within boreholes drilled on the ESF pad.

The proposed MPBH test would include two 6-in. (15-cm) boreholes, air-drilled (with intermittent coring) to the total depth of the ESF shafts. The boreholes can be located 46 to 60 ft (14 to 18 m) to the south-southeast (down dip) of each shaft (Figure 8.4.2-19). The purpose of the MPBH test would be to (1) investigate for perched water (either natural or from existing exploratory hole USW-G4), (2) obtain stratigraphic and rock quality information before shaft construction, (3) establish baseline data on hydrologic properties before shaft construction, and (4) monitor for changes in baseline hydrological conditions during construction of the exploratory shafts. Present plans include long-term monitoring of the proposed MPBHs, in conjunction with other ESF hydrologic testing activities, to determine the actual behavior of the rock mass between the proposed MPBHs and the shafts for comparison with the design assumption that rock mass effects are limited to the zone of influence (two shaft diameters) around the shafts. If the MPBHs are not drilled as currently planned, and if the information is still considered necessary, then equivalent information will be acquired by alternative testing strategies or thorough analyses of available information. More information about the tests is provided in Section 8.3.1.2.2.4.9.

The MP-1 borehole would be near ES-1, and the MP-2 would be near ES-2. The holes are planned to be located in a pillar at the main test level, thereby complying with the 10 CFR 60.15 requirement that, to the extent practical, shafts and boreholes be located where large, unexcavated pillars are planned. The holes would be at least two drift diameters away from any mined openings in the dedicated test area in the ESF. These boreholes would be periodically accessed from the surface for purposes of logging or instrument maintenance while the shafts are under construction.

A third multipurpose borehole could be drilled between ES-1 and ES-2. This borehole would be used to evaluate the effects of fluids used during construction of ES-2 on hydrologic tests to be conducted in ES-1. A decision on the need for a third multipurpose borehole would be made on the basis of additional analysis before constructing ES-2.

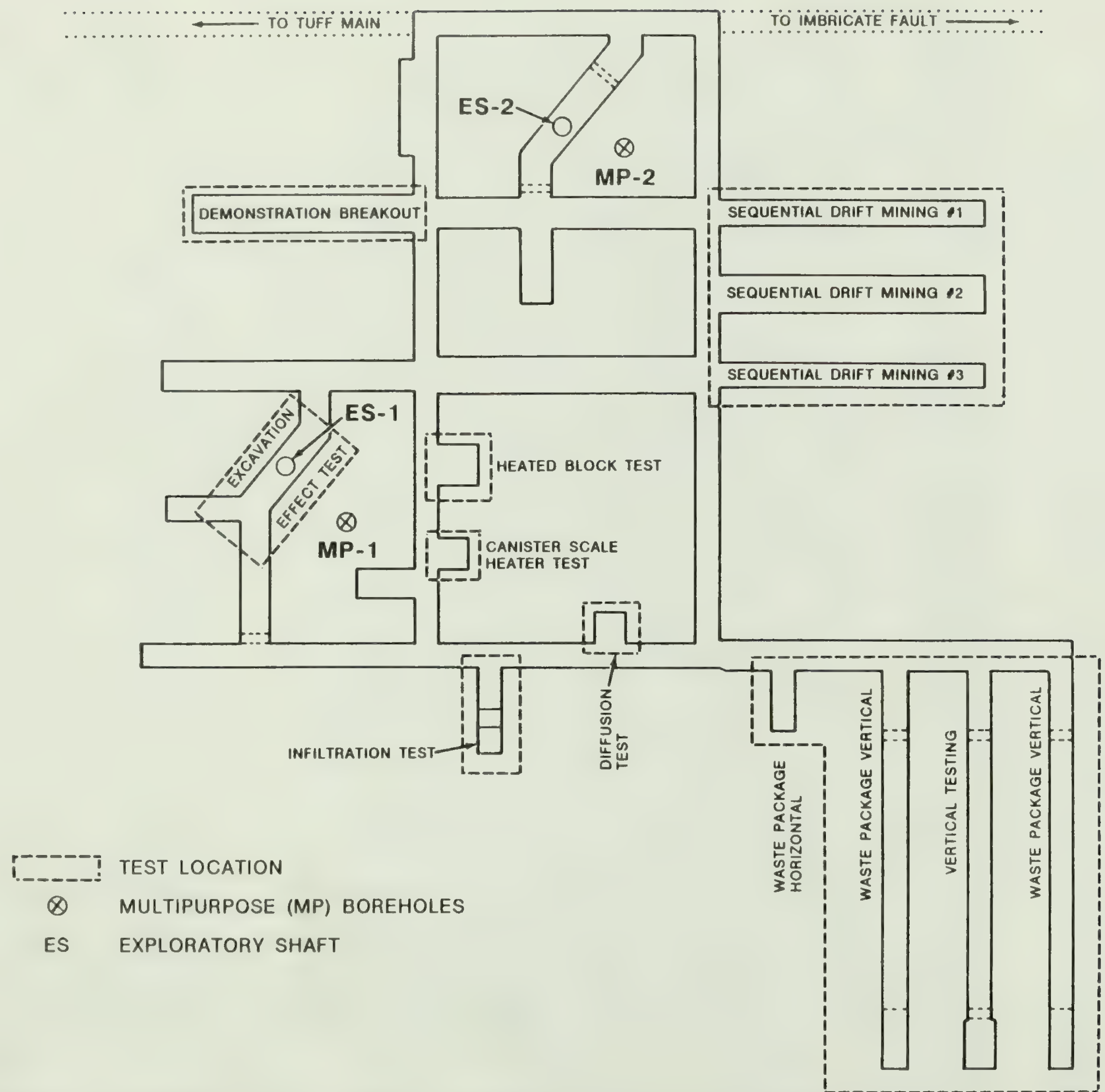



**Figure 8.4.2-19.** Proposed location of multipurpose boreholes at the main test level. Modified from Title I design package (DOE, 1988)

Constraints and zones of influence

Location requirements for the proposed MPBHs include the requirement for long-term surface access for monitoring, the requirement to locate the boreholes at least two drift diameters away from any underground openings, and the requirement to not penetrate the mechanical zone of influence expected to occur around the shafts. A standoff of approximately 60 ft (18.5 m) from the shaft centerline is required to accomplish this. The standoff would be based on the assumption that the MPBH can be drilled with a maximum deviation of 1.5°, which translates to a 28 ft maximum horizontal deviation at 1,050 ft (323 m) depth. The mechanical zone of influence of both shafts would be approximately 1.5 to 2.0 shaft diameters from the shaft centerline (Section 8.4.2.3.6.2). Thus, the shaft zone of influence could reach a maximum of 28 ft (18.5 m) from the shaft. A 56-ft (17.2-m) minimum separation distance between the centerlines of the shafts and the corresponding MPBH would be required to preclude the MPBH from entering the zone of influence of the shaft. The assumption of maximum drillhole deviation would be reviewed and revised as necessary when a drilling method is successfully prototyped. In addition, the hole would be surveyed as drilling proceeds and the option to cease drilling could be invoked if insufficient separation from the proposed shaft location were observed.

Because the testing in the boreholes would involve only monitoring activities (no fluid injection), no additional perturbation to the natural conditions (stress, temperature, moisture, etc.) would result from this activity. However, because of the uncertainty in the location of the drillhole relative to the shaft caused by the potential for deviation during drilling, a zone of mechanical influence would be established to account for the maximum potential deviation of the hole. Thus, a 28-ft radius around the hole would be used as a standoff zone resulting from uncertainty in final location of the hole at any depth.

Summary

These brief descriptions of the ESF testing are based on current test concepts and plans. Design modifications and more detailed planning will undoubtedly result in changes before the tests are actually conducted in the ESF. The study plans for each activity will provide much more detailed information about all the planned ESF tests.

It is recognized that 10 CFR 60.140(b) requires that a performance confirmation program shall have been started during site characterization. However, Section 8.3.5.16 (performance confirmation) describes the DOE's current approach to performance confirmation and explains that certain tests will likely continue after the submittal of the license application. Therefore, performance confirmation must be considered now in ESF design, test planning, and repository design. Specifically, allowance for continued access to the dedicated test area during repository operations and operational flexibility necessary to support follow-on performance-confirmation testing have been considered. These aspects are discussed in Section 8.4.2.3.6.

### 8.4.2.3.2 Exploratory shaft facility integrated data system

The following section briefly describes the ESF integrated data system (IDS). Approximately 20 experiments in the ESF testing program will generate electronic data that must be collected, stored, and distributed. A computer-based central data-collection utility, the IDS, will support the data acquisition and recording needs of these tests. The system will automatically acquire, record, and provide copies of certified site characterization data to each participating organization for data management and analysis. At the ESF, the IDS will allow the principal investigators to control and monitor their tests. The primary purpose of the IDS is to provide the principal investigators with a uniform, controlled, and verifiable data acquisition and recording system that will function reliably and efficiently.

#### 8.4.2.3.2.1 Purpose and Scope of the integrated data system

The data acquisition system will collect measurements from tests distributed throughout the ESF. IDS facilities will be located underground, at the surface, and remotely in the administration and engineering (A&E) building at Area 25 on the Nevada Test Site. Measurement and control capabilities will be provided at the surface, along the ES-1 shaft, in the demonstration breakout rooms (DBRs), and in the experiment drifts of the main test level (MTL) and long exploratory drifts as required. Primary data recording and system control and monitoring will be performed in a dedicated IDS surface facility near the surface entrance to ES-1. User workstations, off-site communications equipment, and data-record duplicating equipment will also be located in the IDS surface facility. System repair and calibration facilities, some user workstations, and some data media storage will be located in the A&E building.

The IDS provides all experiment and common data with accurate time references, protects records for long-term storage, and distributes experiment and common data to the organizations of the principal investigators in a uniform format at required intervals. The IDS will also provide workstations and portable terminals to users for data quick-look and calibration purposes. Any classical data management and analyses performed by principal investigators on their own computers are not within the scope of the IDS. The IDS design will provide for an interface to off-site communication facilities through which each organization's own test data, all common data, and experiment status information will be distributed.

The IDS will begin at the interface between the user's transducers and the data acquisition hardware. Typically this will be a wire connection box or a zone box that contains a thermal reference plate for thermocouple measurements. IDS users (principal investigators) will be responsible for installing, calibrating, and maintaining their own transducers and any associated local support equipment and experiment controls needed for in situ measurements. The IDS will provide excitation sources as required. Simple on-off control signals will be provided for early in-shaft tests, but the IDS will not provide for complex control functions of any tests. In addition to collecting data from test instruments, the IDS will control all common data items. These include zone plate temperatures, IDS housekeeping monitors,

calibration standards, ventilation mass balance, water in/out flow, and surface weather data.

8.4.2.3.2.2 Integrated Data System Description

In its final form, the IDS will be configured as shown in Figure 8.4.2-20. In the early stages of testing, the in-shaft tests and the upper demonstration breakout room (UDBR) and the main test level demonstration breakout room (MTL-DBR) tests will be supported from a reduced-size surface facility, based on single VAX computer. The in-shaft tests and some common data tests will be connected to a PC-based data logger control on the Phase I data bus. The UDBR and MTL-DBR tests will be connected to a minicomputer-based data-acquisition station, which will then transmit the data to the VAX computer on an Ethernet data highway.

To support the main test level (MTL), which contains the bulk of the testing, the system will be expanded. The IDS surface facility will have two microVAX computers for data acquisition and system control, as well as a VAX Series 6000 computer to handle data archiving and user interface requirements. Another microVAX will be installed in the IDS alcove on the main test level to be used as a system workstation, as well as to serve as backup data-acquisition computer in case of failure of the data highway to the surface facility. This computer can act as a backup for up to 5 days of normal data acquisition. Also, each data-acquisition station can record up to 24 hours of data in case of data-highway failure. There will be three separate data highways, shown as Ethernet A, B, and C. Ethernets A and B are redundant data-acquisition links between the data-acquisition systems and the system computers, and Ethernet C is the administrative data link between the user computer and the user workstations. Through this link the user has access to the IDS to enter some data and do limited analysis, but is unable to access or affect the data collected by the IDS in any way.

A microwave link from the IDS surface facility will transmit requested data from the IDS to the user workstation at the A&E building in Area 25, as well as to off-site locations such as the Lawrence Livermore National Laboratory and the Denver Federal Center. Data transmitted in this way will not be certified for site characterization purposes.

All raw data collected by the IDS will be archived on optical disk (write once read many/WORM) media. The master disks will be retained as system records. Each organization's data, plus the common data, will be streamed onto a separate disk, certified, and given to the organization at regular intervals. This data will be certified to be used for site characterization purposes. A 30 to 60 day set of data will be maintained on-line on the IDS Ethernet C for the user to access for quick-look analysis of the test, calibration, or startup purposes. Provisions will also be made to allow connection of organization computers, supplied by the principal investigators to control their tests and analyze the data from their tests. These computers will be located on the main test level near the individual tests.

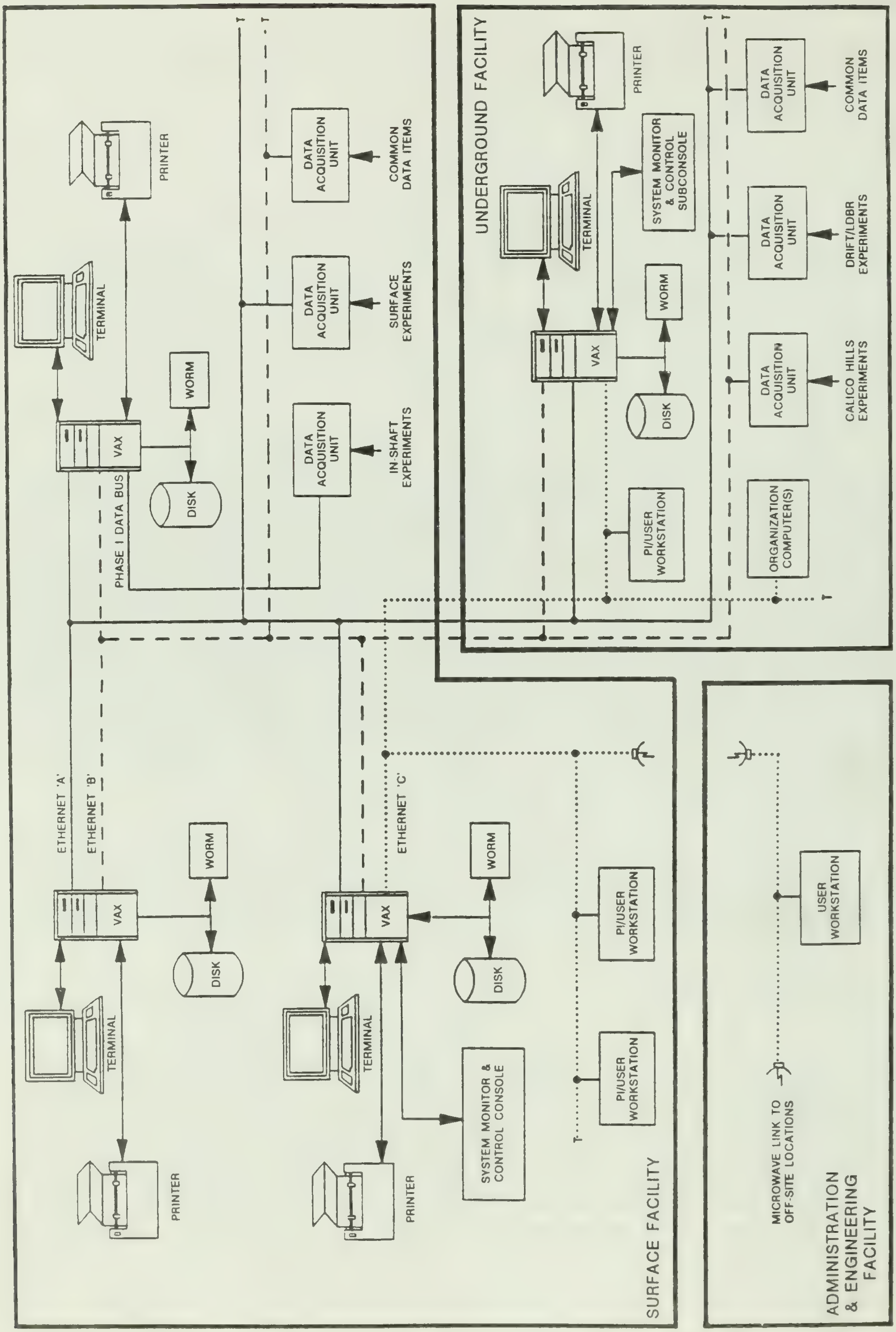



**Figure 8.4.2-20.** Integrated data system block diagram.

In summary, the IDS will provide the users with reliable, accurate, and permanent records of their test data that may be used for site characterization of Yucca Mountain in the license application process to obtain NRC licensing for the high-level waste repository. The system is designed to be flexible and expandable to meet the changing requirements of the users. Accuracy and traceability of the data is the primary objective of the system.

### 8.4.2.3.3 Description of exploratory shaft facility

#### 8.4.2.3.3.1 Introduction

This section describes the exploratory shaft facility. The general arrangement of the surface facilities is presented first. Then, the configuration of the two exploratory shafts is described. Finally, the general arrangement of the main test level and lateral exploratory drifts is presented. Before this discussion, two related topics are presented to provide some background information on the process used by the DOE to control the design of the ESF and on how the current ESF location and configuration were chosen.

#### Control of the design for the exploratory shaft facility

The design of the exploratory shaft facility must incorporate the necessary features to support the tests to be performed in it, and it must complement the repository design, including provisions for controls and features to avoid a significant impact on site integrity. Consequently, the DOE has instituted a design-control process to ensure that the design appropriately considers these factors. This design-control process is part of the application of the quality assurance program (SCP Section 8.6). Requirements and procedures are developed and implemented in accordance with Yucca Mountain Project quality assurance plan (NNWSI QAP 88-9)(DOE, 1988c), specifically under ANSI NQA-1 Element #3--design control.

The design process is depicted schematically in Figure 8.4.2-21. The process begins with incorporation of various regulations into a requirements document. The requirement shown as an example in the figure is 10 CFR Part 60. While 10 CFR 60 is a primary requirement for the design, DOE orders, policies, other applicable federal regulations and mining laws, codes, and safety regulations from the State of Nevada and California are also considered. The highest level of requirements is documented in OGR-B-2, Generic Requirements for a Mined Geologic Disposal System (GR) (DOE, 1986c). Specific requirements for the exploratory shaft are contained in Appendix E of the GR entitled "Generic Requirements for the Exploratory Shaft Facility (ESF) Design, Construction, and Operations." The GR and its Appendix E are developed, baselined, and controlled by the OCRWM program to be consistent with the entire waste management system and to incorporate appropriate requirements of 10 CFR 60 as they apply to the ESF.

The GR requirements are analyzed for specific application to the Yucca Mountain site by the Yucca Mountain Project. This allows the development of a specific set of design requirements--the subsystem design requirements document (SDRD) (DOE, 1987b). The SDRD and a general reference configuration

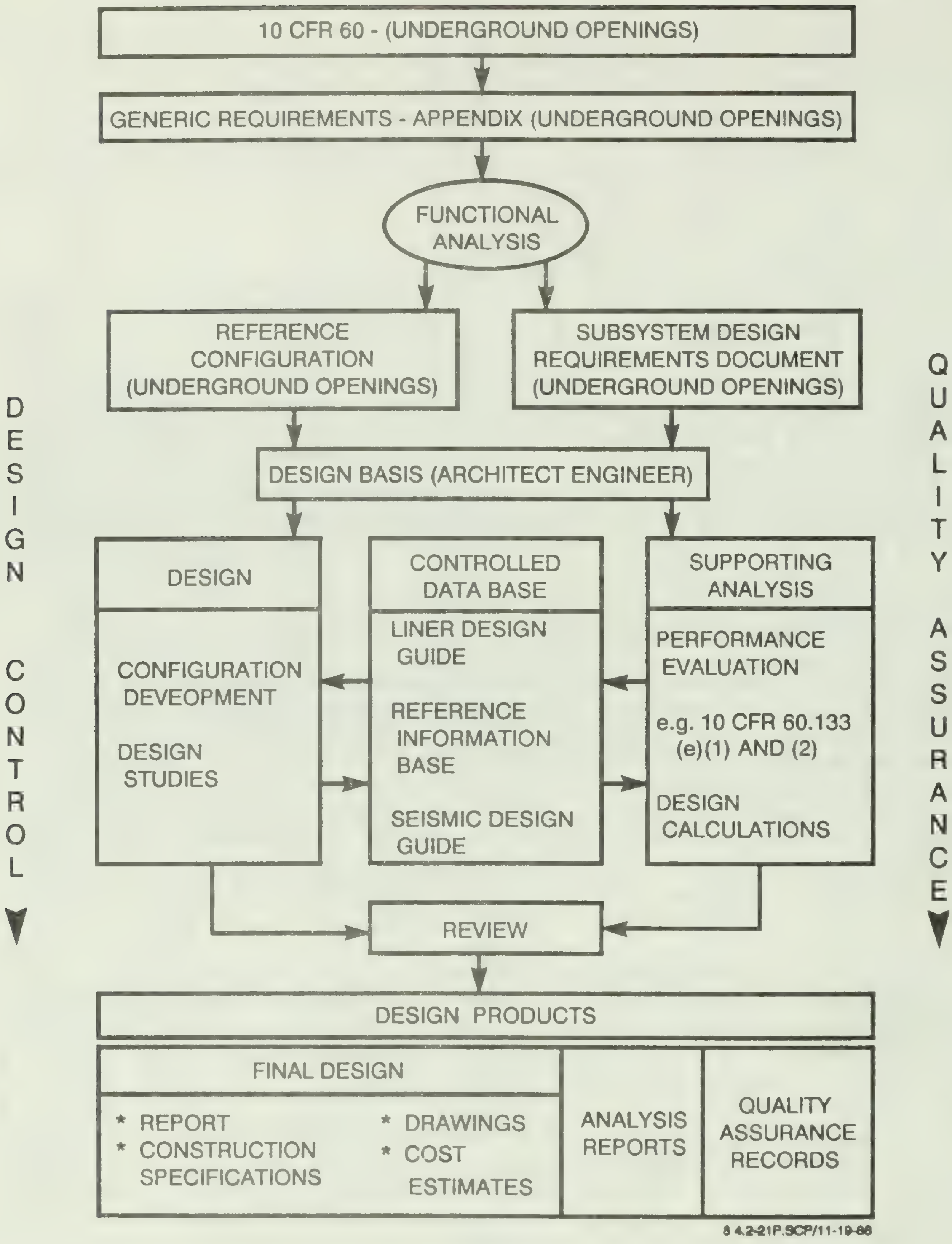



Figure 8.4.2-21. Incorporation of regulations into design process.

for the facility allow the architect/engineer (A/E) to develop a design basis, which is a more detailed description and interpretation of the design requirements in the format of the A/E's internal management system.

The SDRD and the design bases guide the design activities as they proceed. Typically, the design consists of two major elements: (1) the development of the facility configuration and associated studies to define that configuration and (2) supporting analyses to evaluate the design with respect to the requirements. Specific examples of these analyses are presented in Section 8.4.3 to evaluate test interferences and impact on the 10 CFR Part 60 requirements to meet the postclosure performance objectives. The design is developed using data, principally parameters defining rock characteristics, design conditions, and other site-related information. These data are contained in a controlled data base designated the reference information base (RIB). The contents are maintained by a change control process to reflect the current status of knowledge from site characterization activities.

At various times in the design, formal reviews will be conducted to evaluate the adequacy of the design in meeting the requirements. These independent reviews are conducted during Title I preliminary design and Title II detailed design, which are the major design phases, with the participation of various program reviewers. The reviews are open to observation by the NRC and the State of Nevada. Each major design phase results in products, principally a design report, engineering drawings, a cost estimate report, and construction specifications. These products are supported by reports of related analyses and numerous quality assurance records. The products of Title I design, including engineering drawings for underground excavation, surface facilities, and support systems have been used as the basis for the discussion in Section 8.4.

The process just described is controlled by baseline control of major elements, such as the requirements documents, including interface control on the contents of the documents. Examples of interface control include defining the relationship of the ESF configuration to that of the repository and defining the test requirements for each in situ test.

The ESF test requirements are established by the principal investigators (PIs) for each test. The PIs identify standoff distance, space, drilling requirements, utilities, test instrumentation and data acquisition requirements, special construction and operational control criteria, and other special or general test-support requirements to limit test interference and potential impacts on postclosure performance. These requirements, once reviewed and approved by the DOE, become the fundamental bases for the ESF design and are incorporated into Appendix B or C of the subsystem design requirements document (SDRD). In addition, requirements related to the DOE, Federal, and State regulations are identified by the DOE or A/Es and incorporated into the SDRD as applicable. Finally, operational safety requirements that are specifically related to the ESF design, construction, and testing operations are identified and incorporated as appropriate into the SDRD and the design bases.

Application of this design control process, with specific emphasis on incorporation of testing requirements and constraints and the requirements of

10 CFR Part 60, ensures a comprehensive design that is consistent with the DOE's objectives of conducting an effective site characterization program and not adversely affecting site integrity.

Activities leading to the selection of the location and configuration of the exploratory shaft facility

The location of the exploratory shafts and the method used to construct them were selected on the basis of formal screening evaluations conducted in 1982 and 1983. During that same time, two other screening evaluations were underway or completed that are relevant to the exploratory shaft location and construction method selection: the selection of the Yucca Mountain site and the selection of the Candidate Repository Horizon. In 1982, Northern Yucca Mountain was selected from other locations at the Nevada Test Site as a possible repository location, and the decision subsequently verified on the basis of a site-screening evaluation (Sinnock and Fernandez, 1982). These site-screening evaluations considered criteria based upon containment, isolation, construction, and environmental concerns.

The second evaluation examined four distinct formations or stratigraphic horizons of Yucca Mountain that at that time were considered to be potentially acceptable host rocks for a repository. An evaluation was performed to select a single stratigraphic horizon upon which to focus site characterization activities and evaluations of suitability for a repository (Johnstone, et al., 1984). That study ranked each of the four horizons on radionuclide isolation time, allowable gross thermal load, excavation stability, and relative economics. This evaluation was performed simultaneously with the evaluations of the construction method and location of the shaft.

The location of the exploratory shafts and the method used to construct them were selected on the basis of formal screening evaluations conducted in 1982 and 1983 (Bertram, 1984). An Ad Hoc Committee used a Figure of Merit technique to analyze and support two distinct decisions. The first decision was to select a construction method for the shaft from several alternatives available at the Nevada Test Site; the second was to select a location for the exploratory shaft from several candidate sites at Yucca Mountain. The Ad Hoc Committee evaluated the two decisions individually and then combined the results. Screening criteria were developed and their relative importance evaluated. The Figure of Merit technique was then used to evaluate the ability of each alternative to satisfy the criteria. These criteria are tabulated in a summary report (Bertram, 1984).

The objectives of the construction method to be selected were to provide access to the rock unit targeted for repository development so that strata would be characterized in situ and to demonstrate constructability of a large diameter shaft at Yucca Mountain. The selection process considered twelve alternatives (seven of which were unique) developed from combinations of the following: drill the shaft, conventionally mine the shaft, or conventionally mine a decline in the unsaturated or saturated zones. The evaluation criteria for the decision addressed the ability to conduct site characterization, including shaft wall characterization, constructability, cost and schedule, environment and health and safety. In making the decision about the shaft construction method, the Ad Hoc Committee specifically considered the potential for rock damage from blasting but concluded that mining would

allow better control of water losses than would drilling. On the basis of the criteria rankings developed by the committee (Bertram, 1984) the DOE concluded that the exploratory shaft should be mined by conventional methods.

The objective of the exploratory shaft location screening evaluation was to select an exploratory shaft site from which to explore target units within the exploration block. The evaluation emphasized the unsaturated zone but retained the capability to access both unsaturated and saturated target units to both confirm expected favorable conditions and to assess potentially adverse conditions. Furthermore, the objectives included the desire to avoid known areas of potentially adverse subsurface conditions for shaft siting, but to retain the capability to access these areas for testing from the shaft. Another objective was to avoid surface areas where constructing the shaft would result in environmental impacts that could not be mitigated. The site screening evaluation criteria addressed scientific, engineering, environmental, and nontechnical concerns. The scientific criteria addressed offset from structural features (so that the exploratory shaft would not be constructed in areas of fractures associated with the structural features), thickness of rock units and homogeneous physical properties, distance to potentially adverse structures (to enable their exploration), and exploration of as large a volume of rock as possible. The engineering criteria addressed constructability, terrain (including flooding), and compatibility with potential future development of a repository. The evaluation also considered repository compatibility concerns using a preliminary repository design configuration.

The actual screening for exploratory shaft location was applied in two steps: first, a subset of the set of screening criteria was applied to determine preferred areas at Yucca Mountain. Four specific criteria were then used to screen preferred areas: offset from structure, distance to potentially adverse structures, constructibility, and adverse topography and slopes. Overlay maps of exclusionary areas based on these criteria were prepared, and five preferred areas were identified for further screening using the remaining criteria. The site with the highest Figure of Merit is located in Coyote Wash and is approximately 600 ft by 800 ft. The DOE accepted the committee's recommendation to locate the exploratory shaft at that site.

Subsequent to the formal selection of Coyote Wash as the location for the exploratory shaft, two events occurred that have a bearing on the discussions in this section. The first was a decision to enhance worker and user safety in the exploratory shaft facility by providing a secondary means of egress. This decision was made at the time that the environmental assessments were in preparation. Thus, the exploratory shaft facility described in the environmental assessment actually contains two shafts. One is the 12 ft diameter conventionally mined shaft originally considered; the second was to be a 6-ft diameter raise-bored shaft for emergency egress.

The second event related to the shaft location decision arose as a result of Project review of characterization activities in the exploratory shaft facility. The 12-ft diameter of ES-1 was initially established in 1983 on the basis of the understanding of scientific measurements to be made in the shaft and at each of the horizons (520, 1,200 and 1,400 ft), size of equipment, material handling, and ventilation requirements. The initial

concepts for the facility configuration and testing program were developed between 1980 and 1983 to provide access to geologic formations to characterize the subsurface environment, and to provide services to build and operate a small underground facility. The DOE and its contractors raised questions as the environmental assessment was being finalized and the SCP being prepared of whether adequate characterization or representativeness were likely and whether sufficient expansion capability existed with the facility as designed. Specifically, the DOE was concerned about potential safety problems associated with an expanded mining program, the proposed ventilation system design, larger equipment for mining exploratory drifts requiring larger shafts, hoisting capacity, the compatibility of underground configuration for scientific tests with operational requirements (without interference), size of drifts, and compatibility with the repository conceptual design. On the basis of analyses on these concerns and a meeting with the NRC and State to discuss potential changes, the DOE, in June 1987, adopted five recommended changes to the exploratory shaft facility. These were (1) to relocate the shaft collars out of the alluvium and in rock (yet remain within the area in Coyote Wash described in Bertram, (1984)); (2) to relocate the main test level to the 1,055-ft level; (3) to construct approximately 5,600 ft of drifts (rather than drilling) to investigate geologic structures; (4) to expand the main test level complex by approximately 2,500 ft of drifts; and (5) to change ES-2 to a 12 ft-diameter conventionally mined shaft. These changes incorporated concerns raised by the NRC about the location of the exploratory shaft collars with respect to the runoff patterns in Coyote Wash. The location and elevation of the collars were changed to provide further separation from the limits of the probable maximum flood.

This briefly summarizes the activities that led to the current ESF facility configuration. A more detailed summary of the activities, leading to selection and approval of the ESF location and an integrated discussion of events relevant to evolution of the ESF concepts, designs, and location are provided in Gnirk et al. (1988). Subsequent sections describe the facility. The adequacy of the configuration is presented in Section 8.4.2.3.6, while the potential impact of the construction and operation of the facility is assessed in Section 8.4.3.

#### 8.4.2.3.3.2 General arrangement of surface facilities

At this time, existing surface facilities consist of an access road to the ESF site that is paved on the Nevada Test Site except in washed-out areas and a water line and 69 kV overhead power line extending to the NTS boundary. The water is from well J-13 and the power is from the Canyon Substation; both are located in Area 25. In addition, there is a transformer to change the 69 kV power to 4160 V, which is underbuilt on the same power poles. Figure 8.4.2-22 graphically illustrates the arrangement as it exists today. Surface facilities are intended to provide full and independent service to the underground test work.

The major surface facilities consist of pads and roads, buildings, electrical facilities, water, waste water, including mine water and sewer, communication and data management systems, shaft collars, ESF plant and support facilities, hoists and headframes, muck storage, and batch plant. The

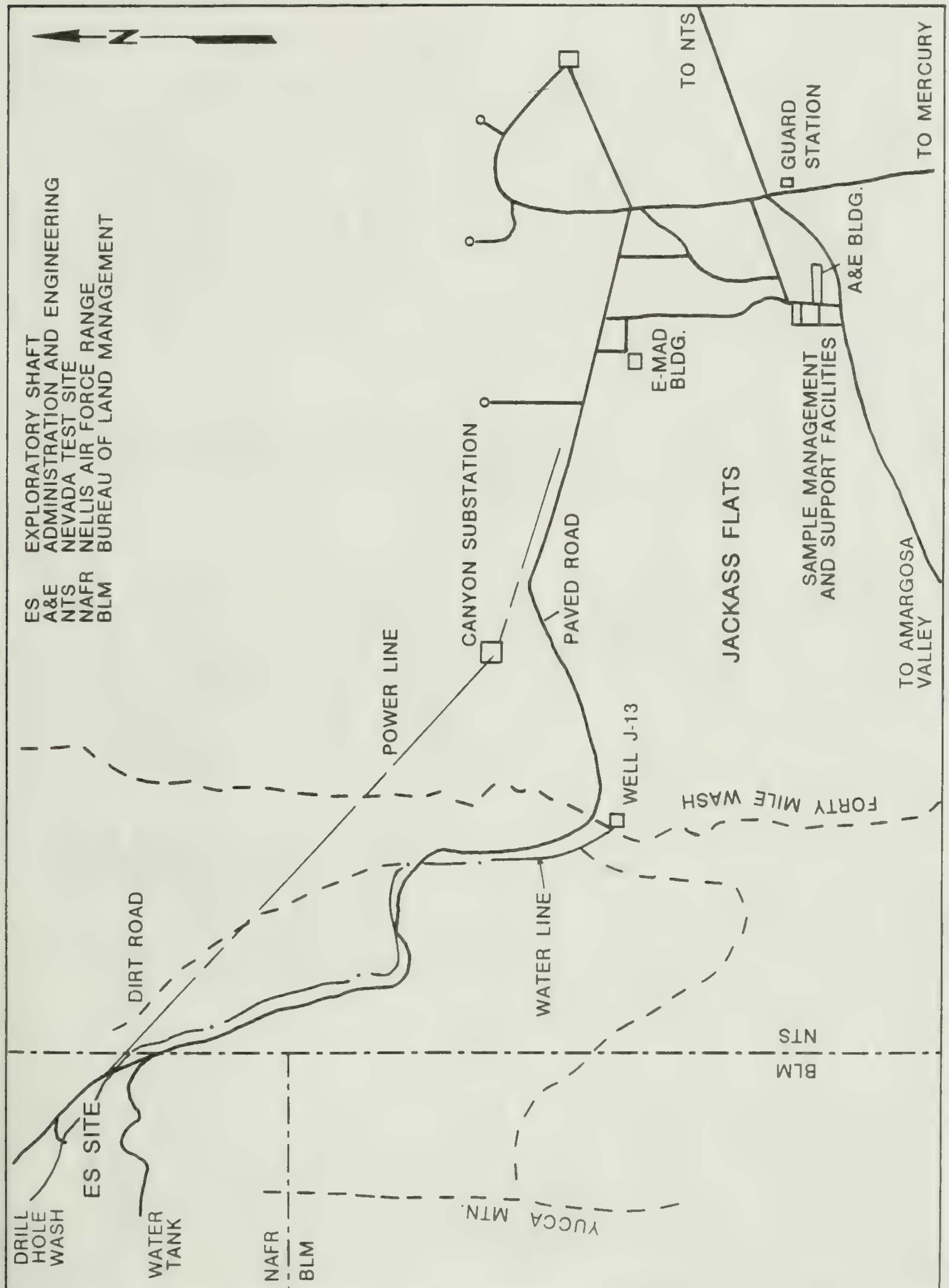



**Figure 8.4.2-22.** General arrangement of surface facilities.

facilities are designed to provide adequate space for construction and testing for the site characterization.

Pads and roads

The pads and roads will be prepared using earth moving equipment such as rippers, scrappers, and dozers. Blasting will be required to remove the hard rock, and controlled blasting techniques will be used to control damage to the rocks surrounding the blasting operations. Such control blasting requires strict control on the use of explosives (e.g., type of explosive to be used might be specified), the amount of explosive to be used, the type of initiation system, and stemming and delays. In addition, special techniques such as angle drilling, cushion blasting, or presplitting or preshearing can be used to minimize potential damages to the surrounding rocks. More discussion of the expected extent of fracturing of the rock during pad construction is provided in topic 12 of Section 8.4.3.2.3.

The blasting controls will be instituted through construction specifications. This can be accomplished by specifying threshold limit of peak particle velocity and frequency. The actual blast will be verified by testing and monitored when the pads and roads are excavated.

Several leveled pads will be required to accommodate the various surface facilities needed for ESF construction and operations. Included will be the main pad for the shafts, headframes, hoisthouse, shops, offices, integrated data system, and power distribution systems. Separate pads will be constructed for the power substation, equipment storage, explosive storage bunkers, a water tank, and muck storage. The concrete batch plant is planned to be situated on an existing pad inside the Nevada Test Site. The general locations of these pads are shown on Figure 8.4.2-23. The existing access road from Jackass Flats to the Nevada Test Site boundary is 24 ft (7 m) wide with a double oil-and-chip surface pavement. This road will eventually be extended to the ESF pad. Other roads shown on Figure 8.4.2-23, will be graded dirt or gravel access routes subject to periodic surface maintenance. Vehicular access, easements, and parking areas on the ESF pad proper, are shown on Figure 8.4.2-24, along with the general arrangement of the surface buildings. Access will be controlled using fences and gates as necessary on the roadways. The natural terrain provides an effective access barrier to the north, west, and south of the ESF site.

Buildings

Buildings on or in proximity to the main pad include space provisions for the project participants and other related functions. A change house, shop, hoist house, and an integrated data systems building are provided. Provisions were made to accommodate mining personnel of 30 people per shift for 3 shifts per day, in the change house, which will also be the location of the first aid station, the Reynolds Electrical and Engineering Company training room, lamp battery room, and the life-safety systems panels. A shop will be provided to support the ESF minor shop functions and responsibilities.

Surface data will be collected in a dedicated building on the main pad in proximity to the shafts. The building will be a pre-engineered metal

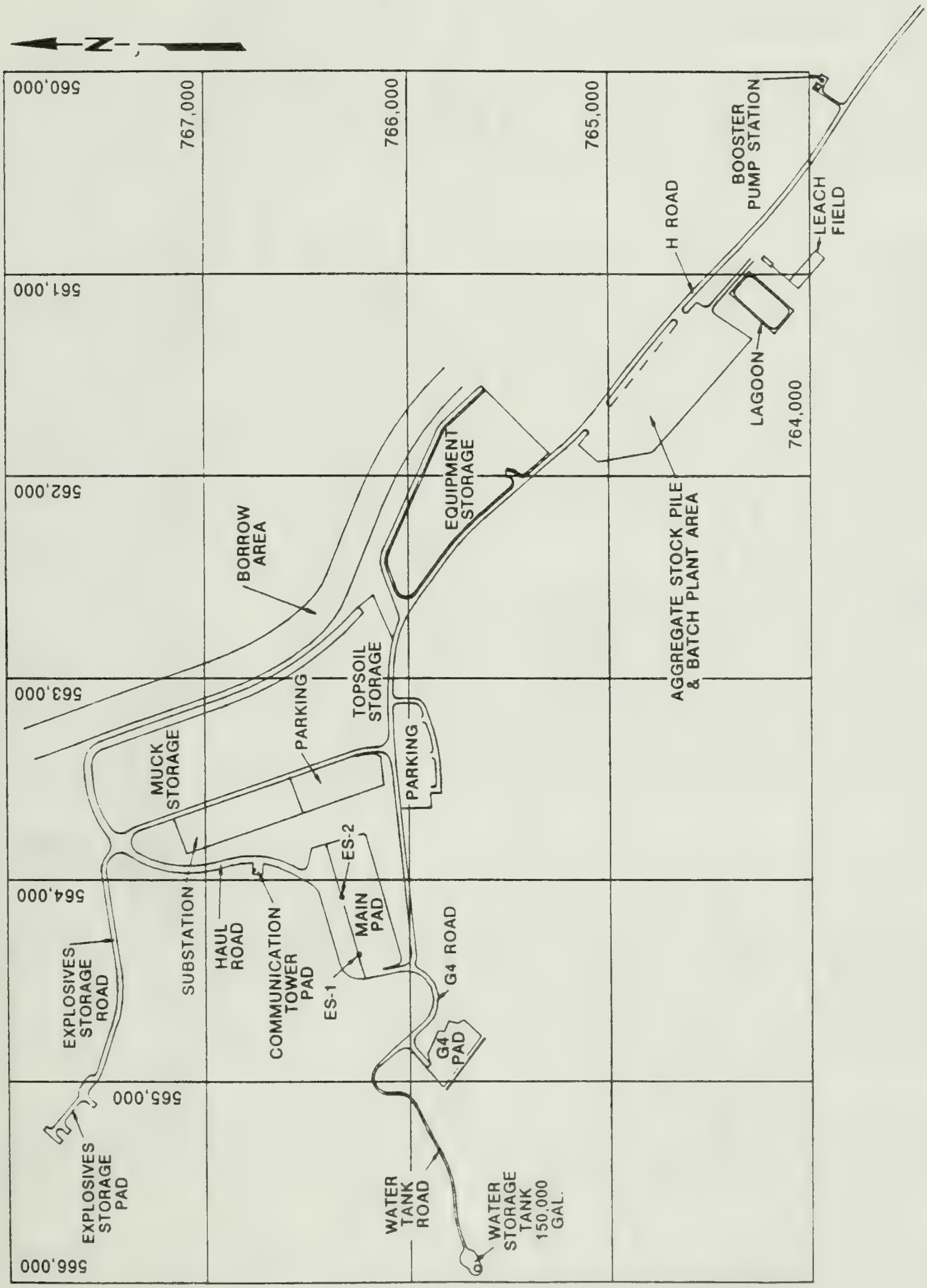



**Figure 8.4.2-23.** Exploratory shaft facility site plan. Modified from Title I design package (DOE, 1988).

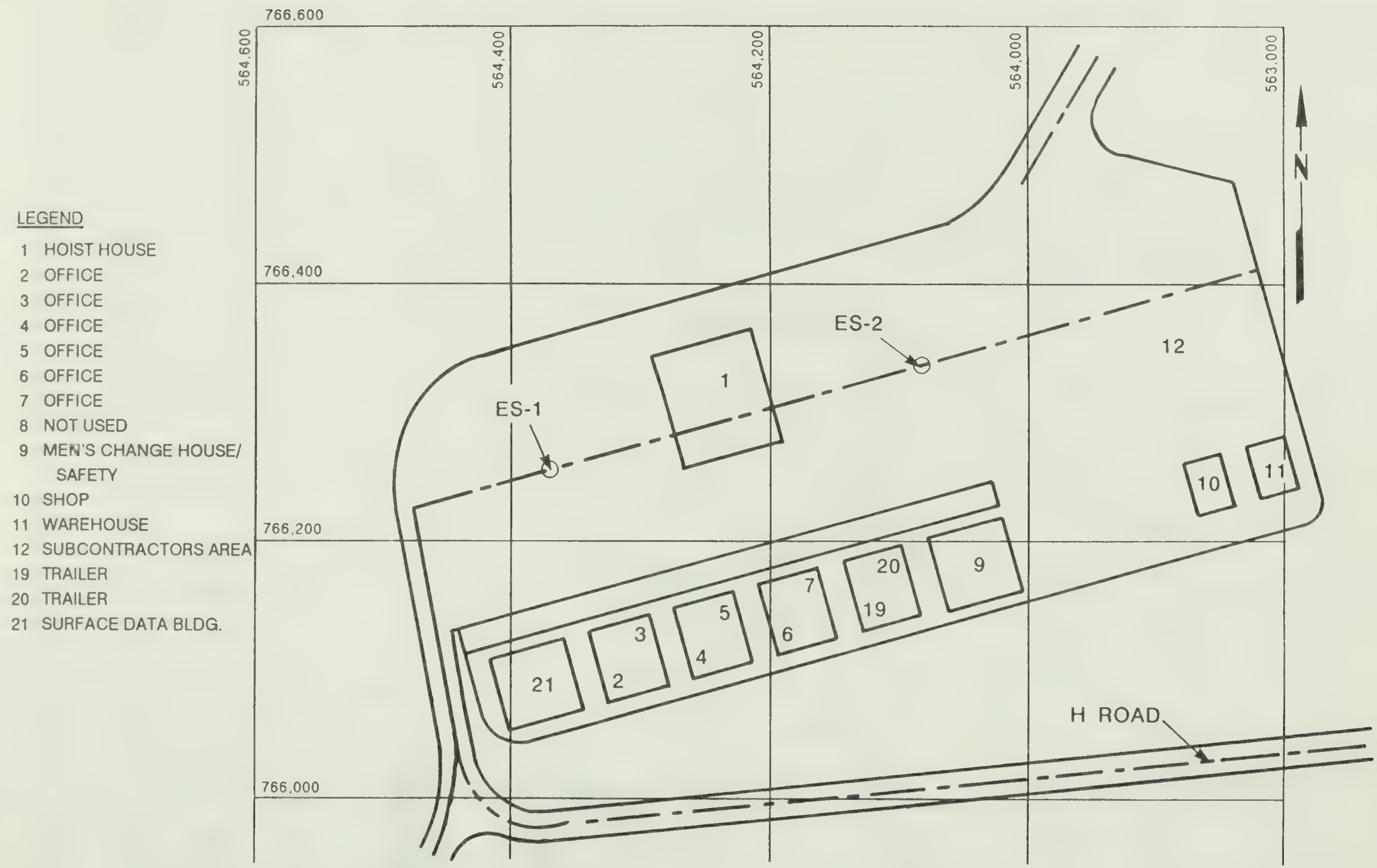



**Figure 8.4.2-24.** Layout of main pad of the exploratory shaft facility. Modified from Title I design package (DOE, 1988).

building with appropriate fire protection. The building will be designed to accommodate and protect the data records.

Warehouse facilities will be located on one of the auxiliary pads. This will consist of a building and protected storage on the pad. Other building requirements include an explosives storage area with bunkers and a pump house to boost the water supply. Again, all buildings will be pre-engineered metal and appropriately sized to the use intended.

Temporary buildings will be assembled or moved onto the ESF site as they are needed during the construction and operations phases. The site pad will accommodate only a limited number of buildings, and, as one construction phase is complete, buildings may be converted for different use or removed from the site. Prefabricated metal buildings will be constructed to provide for change facilities, space for shops, warehouse, and the hoist house. The integrated data system will be housed in a prebuilt modular building. Trailers will be located on the ESF pad and used for office and sample preparation space, and a first aid station. Most functions not directly supporting construction will be conducted from offices and laboratories in the A&E building, the sample management facility, or laboratories in other existing buildings located in Jackass Flats (Figure 8.4.2-22). The A&E building will also serve as a visitors' center.

Three magazines (bunkers) will be constructed for storing explosive materials: one for explosives, one for detonators, and one for primer makeup. The magazines will be located north of the exploratory shaft site and isolated from it by a high hill (Figure 8.4.2-23).

Appropriate codes, standards, specifications, and design bases for the surface facilities are identified and specified in the subsystems design requirements document for the ESF (DOE, 1987b).

Electrical facilities

A surface substation to be constructed at the exploratory shaft site will provide the aboveground electrical supply and power for the underground distribution system. The substation will be supplied from an existing 69-kV overhead powerline that extends from the Canyon Substation in Jackass Flats to the Nevada Test Site boundary (Figure 8.4.2-22). The substation will be equipped with transformers to supply power to the hoists, air compressors, ventilation fans, surface buildings, and the underground facilities.

A powerline will be added to the existing power poles to provide power to the water supply booster pump station located southeast of the ESF site. Night lighting will be provided by pole-mounted area floodlights. Standby electrical power will be provided by diesel generators.

The diesel generators will cover interruptions to electrical systems critical to life safety and data collections. The generators will be sized to the use and be on a demand start. Further backup to critical systems will be provided with uninterruptable power supplies. These will be put on the lines supplying the data collection equipment as determined by the experimenters. New powerlines will be installed to accommodate the facility as

required. The 4,160 V feed will be transformed locally to provide power at the levels required at each use point.

Water

According to current plans, the water supply will be distributed from well J-13 on the Nevada Test Site through an existing 6-mile-long, 6-in.-diameter polyvinyl-chloride pipe buried about 2 ft below grade. The pipeline, which has been constructed in the bed of the old access road to the Nevada Test Site boundary, is adjacent to the new paved road and will be extended to the ESF site. Well J-13 is located approximately 3 miles east of the proposed repository boundary. One pump station is at well J-13, and a booster pump station is about halfway (based on elevation) to the site. Water will be pumped to a 150,000-gal water tank, which will be located west of and above the site at an elevation of approximately 4,330 ft (1,320 m). The water distribution system from the tank will supply water for all needs at the ESF, including fire protection. The fire protection system is designed to meet all applicable codes as specified in the subsystem design requirements document for the ESF (SDRD) (DOE, 1987b). The water supply system will be designed to accommodate reasonable changes in the surface and underground facilities. Drinking water will be separately provided to the underground workers. The water used will be tagged. Water controls will be installed to ensure that failure of the distribution system will not be critical. The types of control planned are

1. Pressure reducing valves utilized to reduce the high pressure head present in the shaft piping.

2. Line break valves placed at strategic locations to automatically shut in the event of excess flow due to damaged or severed water main piping.

3. Pressure relief valves located downstream of pressure regulators for safety. These relief valves will drain to the waste water system if ever used.

4. Manual shutoff valves located as required to provide isolation of piping sections for maintenance or component inspection.

5. Water hammer arrestors used to minimize hydraulic shock caused by sudden reduction of flow in a piping system.

Waste water

The disposal of the waste water is divided into two systems. Sanitary waste from about an expected 200 persons will be disposed of in a septic tank leach field system. The disposal point will be offsite and downhill from the ESF, well away from the water supply and all personnel activity. The other system is the mine waste water, which it will be processed through a separator to remove oils and disposed of in a settling pond. This system will handle the capacities of both mining water and naturally occurring water expected from the shaft. Permits will be required for both systems and the disposal systems will be built to code.

The settling and evaporation pond for mine waste water will be used to contain all the waste fluids pumped from the underground facility. The unlined mine waste-water settling pond will be located east of the exploratory shaft 2,000 ft beyond the repository block boundary. Drilling fluids that will be used underground, including air-water mist, bentonitic mud with water control agents, and polymer foam, and any other no-sewage water used for construction, will be pumped from the underground facility to this pond. The mine waste water will be tagged with a tracer, and treated before being discharged into the tail end of Coyote Wash. To support this design, an analysis will be performed to ensure all concerned parties that this system will not impact site characterization. The design life for the pond will be a minimum of 25 years, and it will be able to hold approximately 375,000 gal ($1.4 \times 10^6$ L) of waste water. Top soil removed during construction of the pond will be placed in a topsoil storage area and saved for eventual reclamation of the area once the pond is no longer used.

Communications and data management system

The ESF communications system provides telephone communications to the outside world, a life-safety warning system, an underground paging system, intercoms, and a hoist operators communication system. The system is designed as a unified system to provide the maximum flexibility to the operation. The life safety system will be centered around the supervisor's office, which will house the annunciators and response controls. Both audio and visual warning will be provided. The hoist operator will have verbal communication, the traditional bell system, and a closed circuit TV system to provide visual indication of the landing areas. The system is being designed as state of the art in all respects using proven equipment built to the most stringent of the applicable codes such as DOE order 6430.4, chapter VII. The data produced by various tests described in Section 8.3.1 will be collected by an integrated data system (IDS) as described in the Section 8.4.2.3.2. The IDS will be located near the shaft on the main pad.

Shaft collars

The shaft collar is a 16-foot deep structure that (1) provides a stable foundation for the headframe assembly and hoisting sheave wheel assembly and conveyance system over the entire range of hoisting system functions, operations, and requirements; (2) provides support for shaft sinking equipment over the range of conditions encountered during construction; and (3) accommodates penetrations and structural mountings for the conveyance system, utilities, instrumentation, and ventilation used for the underground facility. The collars for both ES-1 and ES-2 will be constructed using similar design and construction methods. Both shaft collars are located in bedrock, and the initial excavation will be accomplished by controlled drill and blast techniques. The broken rock will be removed mechanically using a crane with clamshell bucket. The collar structure will consist of reinforced concrete extending approximately 1 ft above and 15 ft below the finished grade (Figure 8.4.2-25).

Exploratory shaft facility plant and support facilities

The ESF plant and support facilities provide the aboveground equipment and systems to support the subsurface construction. Major equipment provided

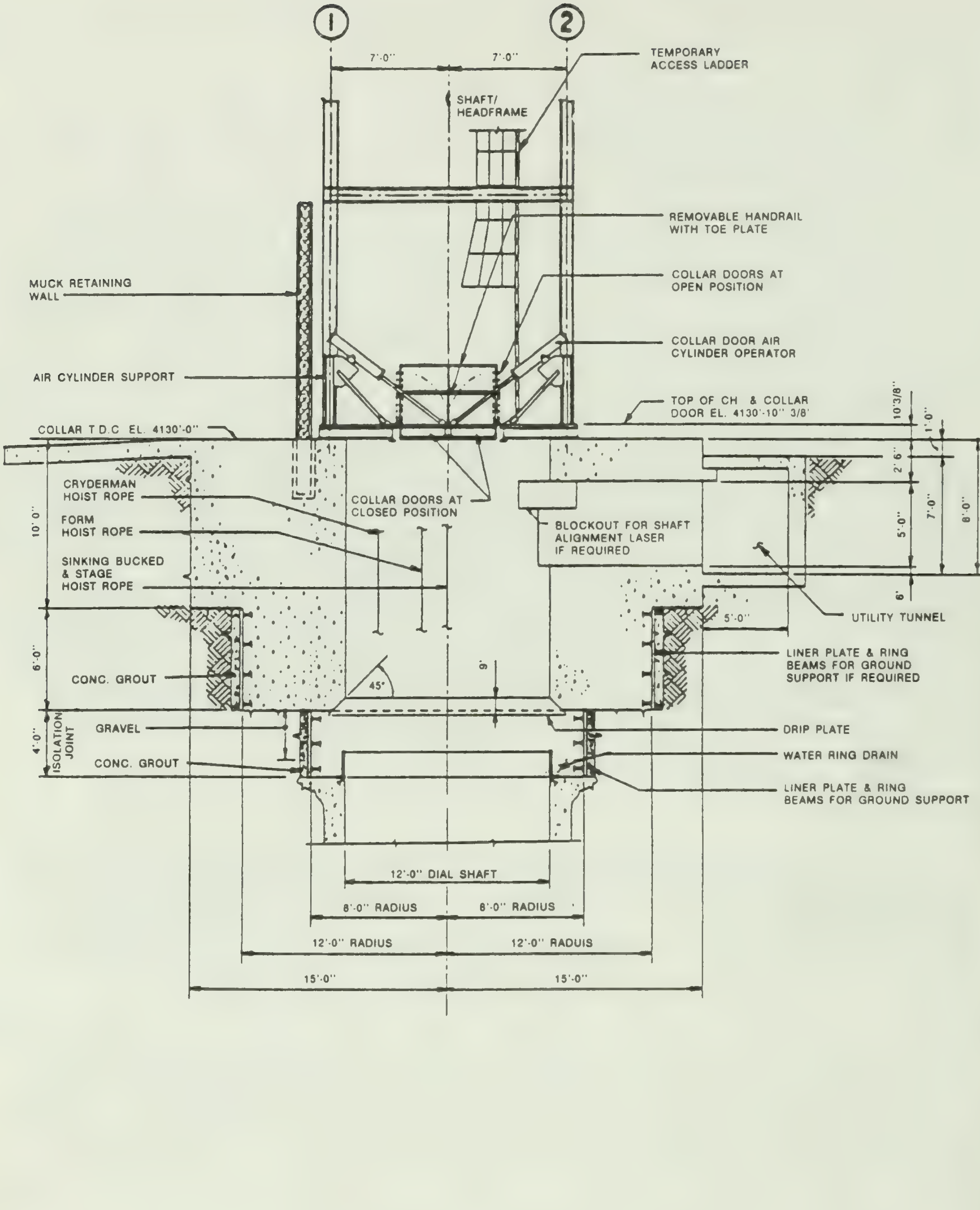



**Figure 8.4.2-25.** Design of shaft collar and headframe foundation. Modified from Title I design package (DOE, 1988).

in the plant includes ventilation fans with ductwork through the shaft collar; air compressors and supply lines to the shaft collar; water-supply piping to the shafts; and waste-water piping from the shafts to the mine waste-water pond. Other equipment may also be required. Major construction support facilities in the Title I design include the concrete batch plant, muck-storage area, mine waste-water storage pond, laydown areas for supplies and equipment, explosive magazines, shops, warehouses, hoists, and headframes (Figure 8.4.2-23).

The ventilation system will be designed according to the subsystem design requirements document for the ESF (DOE, 1987b). Intake, exhaust, and distribution facilities will supply and exhaust required quantities of air to and from underground working areas for personnel health and safety. Systems will be provided to continuously monitor the underground facilities for radon, methane, oxygen, carbon monoxide, temperature, humidity, and air speed.

A concrete batch plant will provide for the storage and mixing of materials for concrete and grout during the ESF construction activities. Concrete will be used for building foundations and for shaft collars and liners. Approximately 1 acre will be used for the batch plant at a location beyond the proposed repository boundary (Figure 8.4.2-23). Crushed rock, sand, and cement will be temporarily stored in this area while the ESF is being constructed.

Hoists and headframes

The hoists, hoist house, and headframes for both ES-1 and ES-2 shafts will be installed and erected following the construction of the shaft collars (Figure 8.4.2-26). The hoists will provide the necessary hoisting capacity for muck removal and for personnel and material transport to and from the surface. The hoists will be outfitted with standard controls, brakes, and other safety systems. Details of the hoist systems, such as the firewall between hoists, are included in the Title I design. Emergency egress is provided using redundant systems including two hoists, which can serve as a backup to each other, and a standby power system available in the event of a power failure. A 42-in.-diameter emergency torpedo cage with a capacity of four persons complete with truck-mounted self-contained escape hoist system (powered by its own diesel engine), controls, safety features and telescoping boom pivoted in the vertical plane, can be made available to transport personnel out of either shaft in case of a serious emergency resulting in no power to the main hoists during sinking and operational phase. This system is most likely to be used during emergency situation when no other conveyance is functional. If neither hoist is functional, the ladderway provided in ES-1 can also be used for emergency egress.

Muck storage

The muck-storage area will be located east of the exploratory shafts (Figure 8.4.2-23) and beyond the proposed repository boundary. The rock debris, removed during the construction of the shafts, the main test level operations area, and the exploratory drifts, will be hoisted to the surface and hauled to the muck-storage area. This area was selected because it would allow for expansion of the muck-storage pile if additional mining were

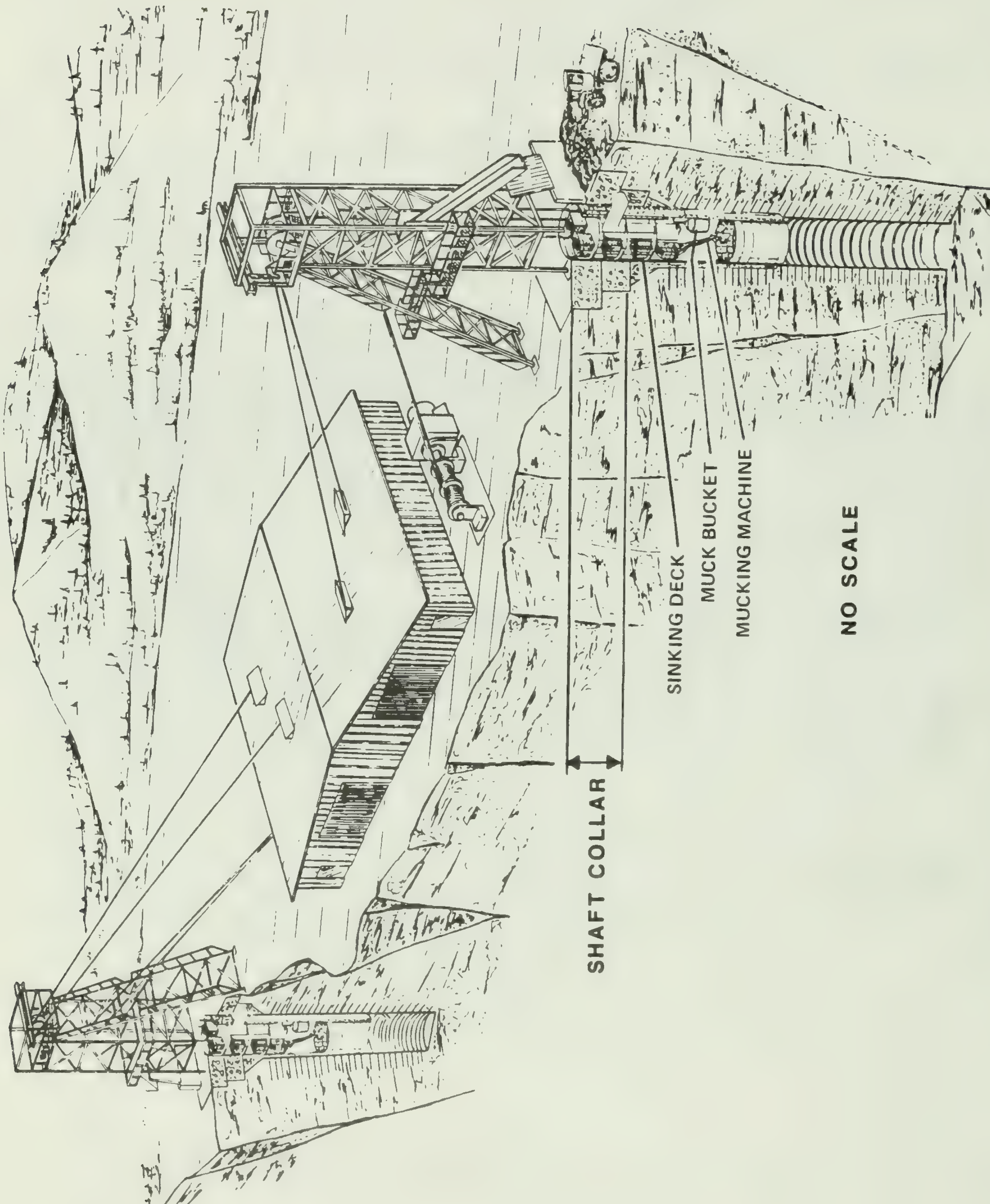



**Figure 8.4.2-26.** Typical hoist, headframe, and collar.

necessary. The area will accommodate more than the 160,000 $yd^3$ (122,400 $m^3$) of rock debris that is currently planned to be produced during shaft and drift mining of the ESF. Dust from the handling and storage operation will be controlled using appropriate dust suppression techniques.

8.4.2.3.3.3 General arrangement of ES-1 and ES-2

In preparing the arrangement for ES-1 and ES-2 as well as the subsurface facility, adequate consideration has been given to the design and layout of a facility that will allow for the characterization of the site to provide needed data and information. Various regulatory concerns and the requirements of DOE orders have been incorporated into the facility design, and the design meets NRC 10 CFR 60 requirements, MSHA requirements, and State of Nevada mining rules and requirements.

The ES-1 has been designated as the scientific shaft. The excavation cycle in the shaft will consider the needs of the investigators to ensure that the expected data from the planned tests are procured. As discussed in the introduction to 8.4.2.3.1, no plans exist to duplicate tests performed in the ES-1 except for geologically mapping the ES-2 shaft. If perched water is detected in the ES-2, then it will be monitored and tested.

The subsurface facilities are carefully designed to provide access to various test locations. The specific test locations are based on requirements identified by the principal investigator and are identified in the SDRD (DOE, 1987b). The main test level (MTL) is designed with capabilities to support the requirements of the planned tests. The designated test areas in the MTL are subject to acceptance by the principal investigator in accord with test acceptance criteria. The excavation will be conducted so that ongoing tests will be unaffected by concurrent mining for future tests.

The ES-1 and ES-2 shafts are centrally located on the ESF pad with a common hoist house between shafts (Figure 8.4.2-26). The shafts are 300 ft apart on an approximately east-west alignment, with ES-1 to the west. Both shafts will have a finished inside diameter of 12 ft and will be lined with concrete. The ES-1 shaft will be sunk to a total depth of approximately 1,105 ft (337 m) from the surface. Shaft stations are provided at the upper demonstration breakout room (UDBR) and MTL. There will be a tailshaft of approximately 50 ft below the MTL to accommodate the conveyance overtravel, crash beams and sump.

The ES-2 shaft will be sunk to a total depth of approximately 1,150 ft (352 m) from the surface and will have shaft station and muck handling facilities at the main test level. A tailshaft of approximately 102 ft (31 m) below the main test level is provided to accommodate the skip loading pocket, conveyance overtravel, crash beams, spillage collection hopper, and sump. A schematic vertical section of ES-1 and ES-2 is presented in Figure 8.4.2-27. This figure also shows the tentatively selected depths for several of the tests that are planned to be conducted while the ES-1 shaft is being sunk. Additional information about these tests is presented in Section 8.4.2.2.3.

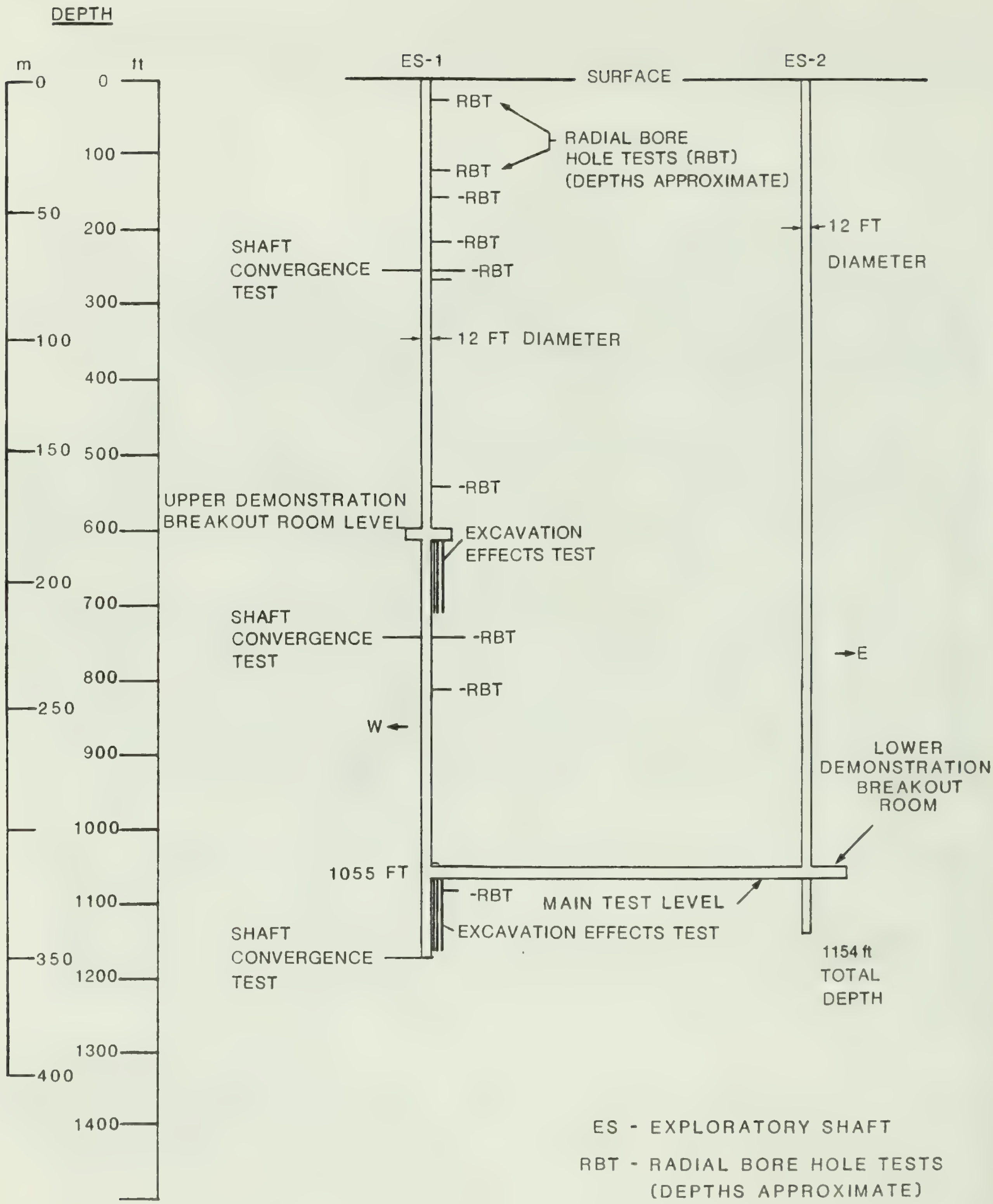



**Figure 8.4.2-27.** Schematic cross-section of exploratory shafts 1 and 2.

After shaft completion, each shaft will be outfitted (conveyance guides, steel supports, ladderway, ventilation plenum, electrical/instrumentation and mechanical utilities) starting from top to bottom. Figures 8.4.2-28 and -29 show typical shaft cross-section arrangements for ES-1 and ES-2, respectively. The arrangement reflects different functional requirements related to ventilation, muck haulage, safety, and testing. These requirements are documented in the subsystems design requirements document for the ESF (DOE, 1987b).

Industrial safety considerations

The following industrial safety related considerations were used in developing the general arrangement:

1. Locate the two shafts to provide rapid emergency egress from the testing area.

2. Separate the shafts so that the refuge chamber shall be readily accessible from both shafts.

3. Provide at least 100 ft (30 m) of standoff distance at the surface from the shafts to flammable materials, including vegetation above the high wall.

4. Locate the shafts to minimize the size of the high walls and potential mechanical interference between the two shafts.

5. Separate the shafts so that an adequate shaft pillar will be available.

6. Locate the shafts such that safe terrain conditions are maintained.

Operational considerations

The operational considerations used in developing the general arrangement are as follows:

1. Hydraulic isolation was considered important but cannot be demonstrated conclusively at this time because of the uncertainties in the hydrology of the area. Each shaft must determine its own water balance because hydraulic measurements in tests associated with the test or located nearby will probably be more affected by water introduced in the shaft than by water movement caused by the presence of the other shaf

2. Space shafts to maintain reasonable distances for power cabling, instrument cabling, and water piping as well as to provide for redundancy in mine water discharge.

3. Locate ES-1 and ES-2 such that the collars are in bed rock and the surface topography allows proper drainage.

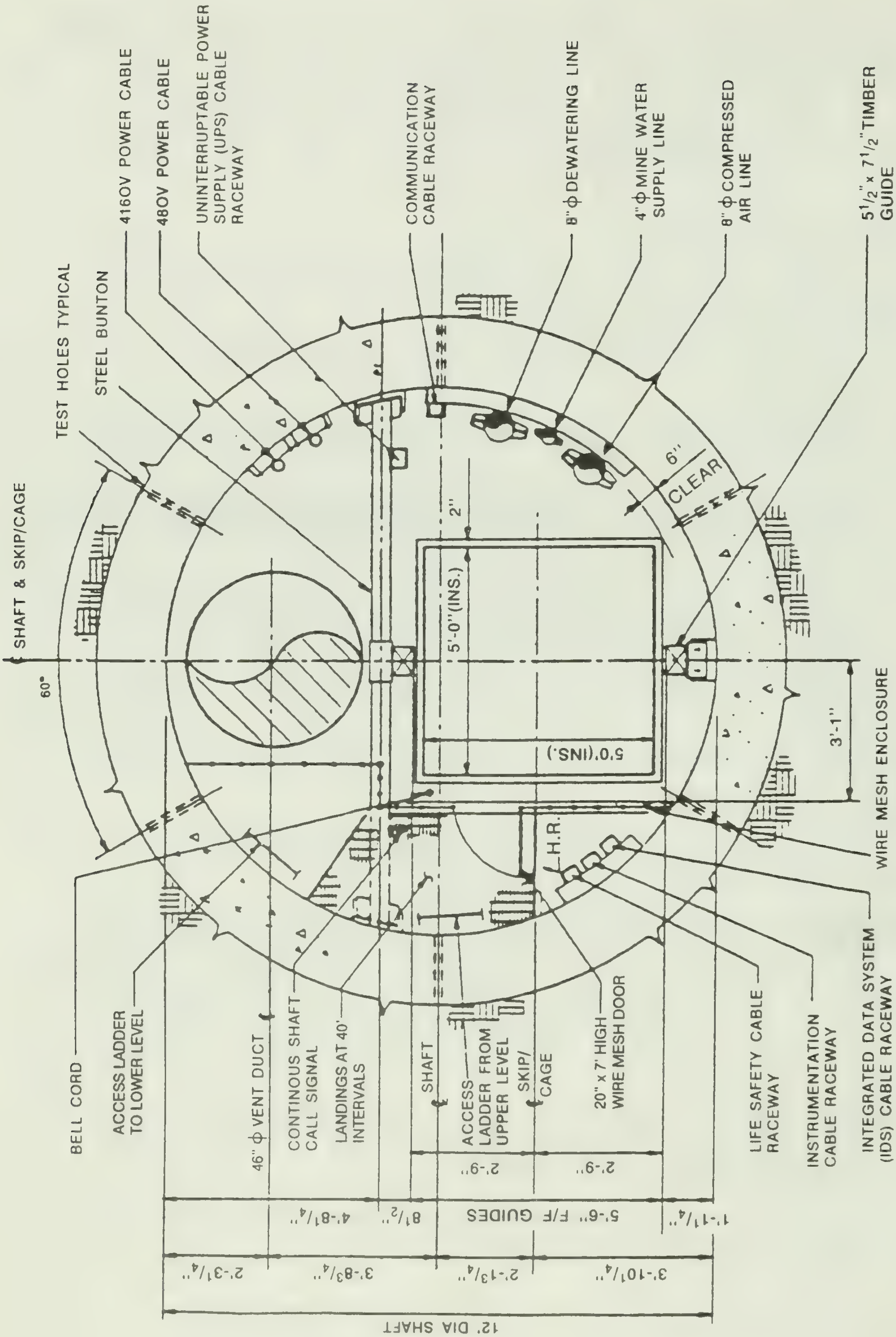



**Figure 8.4.2-28.** General arrangement of internal structures of exploratory shaft 1. Modified from Title I design package (DOE, 1988).

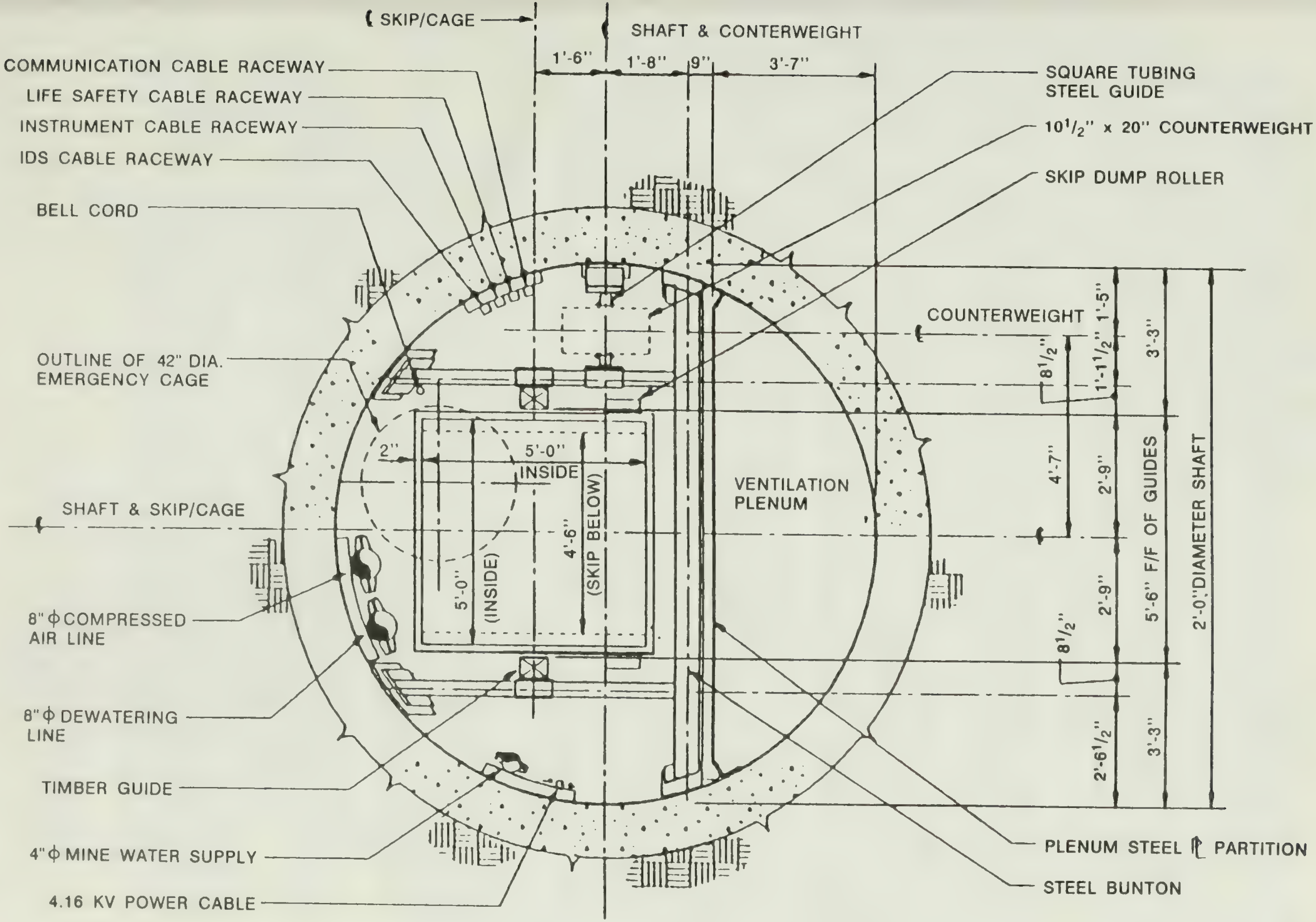



**Figure 8.4.2-29.** General arrangement of internal structures of exploratory shaft 2. Modified from Title I design package (DOE, 1988)

4. Locate ES-2 as close to the ESF dedicated test area boundary as possible (near panel access drift) but provide adequate shaft pillar and allow room for dumping station, operating area, and shaft furnishings.

5. Orientation of surface topography and conditions determines the orientation of shaft furnishings, i.e., strike of Dead Yucca Ridge essentially sets the orientation of hoisting. Given the location of ES-1, ES-2 must be located along the strike of Dead Yucca Ridge to allow for required pad dimension.

Once the shaft locations were determined on the surface and relative to the dedicated test area boundary underground, the general arrangement of the main test level (MTL) was determined based on the following considerations:

1. Need to separate testing from shops, training, and operations areas.

2. Flexibility for experiments.

   a. Required areas for expansion for future testing.

   b. Location of test drifts and alcoves depend on rock conditions and joint orientation that are uncertain until those areas are mined. Flexibility is required for experiment locations and, in some instances, drift orientations.

3. Main test level requirements--provide adequate isolation of tests and provide access for continued mining and construction activities. The MTL provides facilities for the excavation of test areas.

   a. Develop MTL as necessary to provide adequate separation of experiments (Section 8.4.2.3.6).

   b. Certain tests, such as the infiltration test, require separation from any wet mining or drilling activities.

   c. A minimum of two drift diameter standoff distance from mains and repository drifts along the ESF boundary is required.

   d. Test-to-test separation requirements include considerations of possible thermal zones, stress-altered zones, hydrologically altered zones, extent of instrumentation beyond the drift or alcove, and requirements to be isolated from mining or construction activities.

4. Operational schedule: operational areas and facilities need to be mined first before experiment drifts (hence should be located between and close to shafts). Limited amount of mining is allowed (principally the MTL-DBR) before shafts are connected.

5. Ventilation requirements affect room layout and main drift locations.

Finally, the individual experiment locations were selected using selection criteria provided by the principal investigators and related to potential for construction to test interference, test-to-test interference, or operational convenience. The test locations were needed by the A/E to make realistic studies of ventilation requirements, utility needs, mining equipment requirements, etc., and to be able to make reasonable labor, schedule, and cost estimates. The test locations remain to be confirmed by the principal investigators following inspection and consideration of specific acceptance criteria. Even if the exact test locations move somewhat, the planning basis should remain generally accurate with this approach.

#### 8.4.2.3.3.4 General arrangement of the main test level and exploratory drifts

The main test level (MTL) consists of all excavations made from either shaft at the repository horizon and includes the long lateral exploratory drifts and dedicated test area. Figure 8.4.2-4 (Section 8.4.2.3) shows the location of the ESF and long lateral drifts. Specific features of interest on this figure include

1. The boundary coordinates for the dedicated main test level area, coordinates C, D, H, and J on the figure. These coordinates locate the corners of an approximately square area in which the ESF facilities and any drillholes or drifts supporting testing will be contained (excluding the long lateral exploratory drifts used for investigating geological features). This area is dedicated to subsurface testing consistent with repository design.

2. The locations of the common points of the ESF and the repository.

3. The estimated locations where the lateral exploration drifts will intersect the target geological features; namely, the Ghost Dance fault to the northwest, the Drill Hole Wash structure to the northeast, and the imbricate normal fault zone to the southeast of the ESF core facility. The locations use dashed lines to indicate the range of potential intersections based on subsurface projections from the surface for these structures.

Approximately 4,000 ft of drift mining are required to construct the dedicated test area of the ESF. An additional 5,600 ft of drifting will be required to construct the three long lateral exploratory drifts.

Figure 8.4.2-30 presents the current (Title I) general arrangement for the main test level of the ESF. The arrangement and dimensions of the various openings may change as additional design or operations analyses are completed. The location and orientation may also be modified as the interaction between characterization activities and construction phasing are considered further.

The main test level of the ESF includes approximately 4,000 ft of drift length to be used for the support of mining operations and for testing. The drifts are arranged such that the mining of the exploratory drifts, which

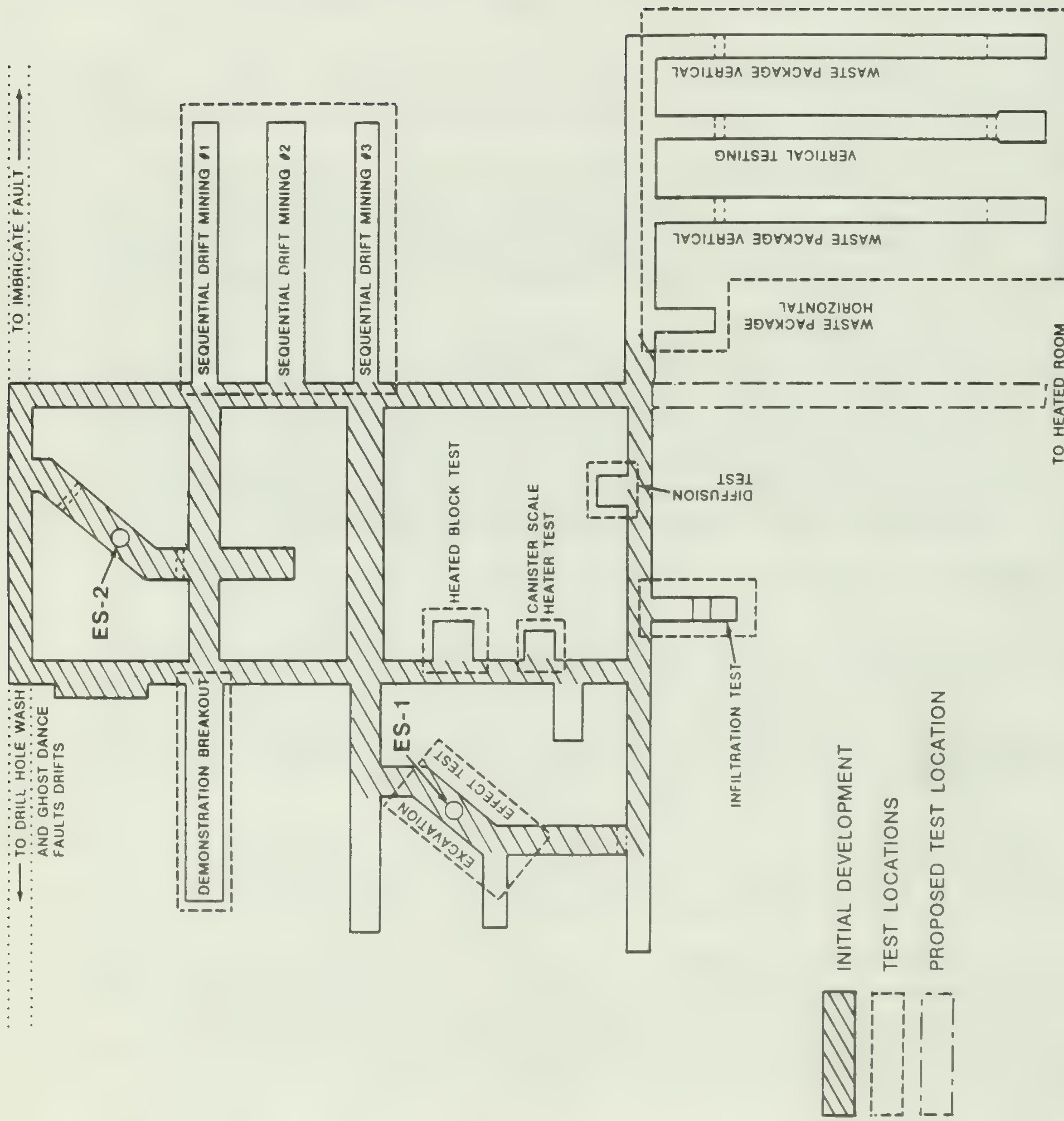



**Figure 8.4.2-30.** General arrangement of the main test level area.

occurs after the central testing area is essentially complete, will minimally impact the testing operations. The locations of the test alcoves shown on Figure 8.4.2-30 are established commensurate with the constraints and zones of influence described in Section 8.4.2.3.1. For some tests, confirmation of location at a particular place in the main test level will be made based on the results of physical examination of the local rock features exposed in the main access drifts (cross-hatched in Figure 8.4.2-30). The final locations and orientations will be determined based on specific test acceptance criteria. The acceptance criteria are likely to include variables such as mining method used (dry vs. wet), blast damage, proximity to operations (muck hauling), test-to-test interference, test duration, geologic features, fracture frequency, drift and fracture orientation and concentration of any tracers found in pore-water or fractures. This approach has been taken to provide substantial flexibility to locate the tests within the ESF main test level.

The long exploratory drifts are shown on Figure 8.4.2-4 and extend outward from the ESF to the imbricate normal fault zone to the east, to Drill Hole Wash to the North, and Ghost Dance fault to the West. Access to the long drifts for mining operations and testing is from the ESF operations area, immediately north-northeast of ES-2 (Figure 8.4.2-30). The exploratory drifts are located so that they are compatible with the conceptual repository design and can achieve their principal objective of accessing these potentially important geologic features for purposes of characterization.

The height and width dimensions of the long drifts will vary from 14 ft by 14 ft to 19 ft by 25 ft with the larger dimension in selected sections where geomechanical tests at full repository-scale are planned. Cross sections, a plan view, and an elevation section of the drift to the imbricate fault zone are shown in Figure 8.4.2-31. The dimensions shown in this figure are typical of each of the three drifts; however, their grades will vary to match grades in the repository conceptual design (Chapter 6 describes the repository conceptual design.)

### 8.4.2.3.4 Description of exploratory shaft facility construction operations

This section briefly describes various stages of construction operations, and Figure 8.4.2-32 shows a summary level exploratory shaft facility summary logic diagram. The construction sequence essentially consists of preparing the site and shaft collars, erecting the headframes and hoists, mining the shaft, and developing the main test level for the test areas. As described in Section 8.4.1.1, a phased approach to implementing site characterization in the ESF is being used by the DOE to continually evaluate the adequacy of the testing configuration and the impacts of the testing activities. Similarly, controls, such as those identified in Section 8.4.2.3.3.1, will be in place to ensure that conditions encountered during ESF construction are adequately reviewed and factored into the experimental program and the remaining construction. These reviews and evaluations will also allow the opportunity to provide information to the NRC, the State of Nevada, and other interested parties.

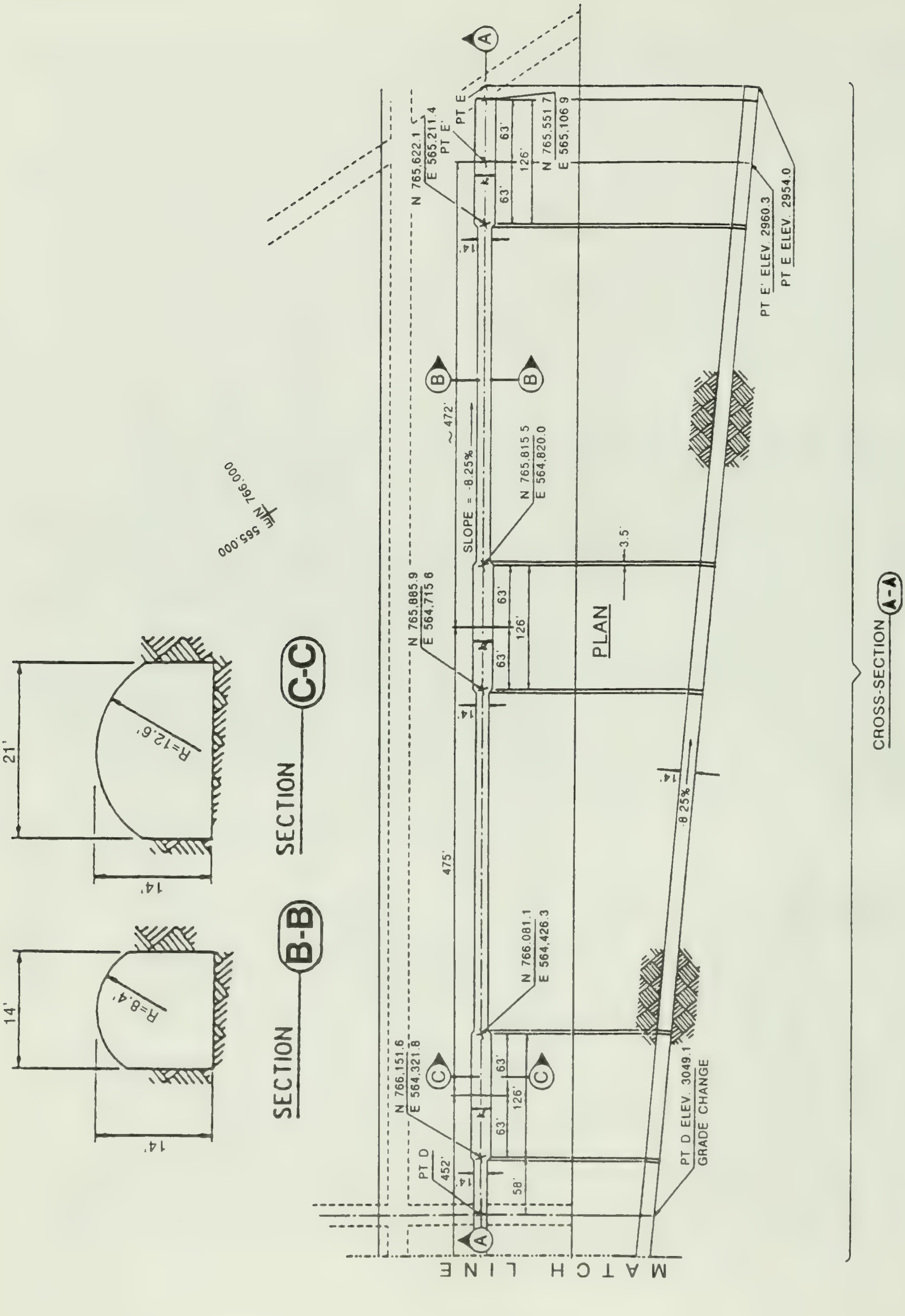
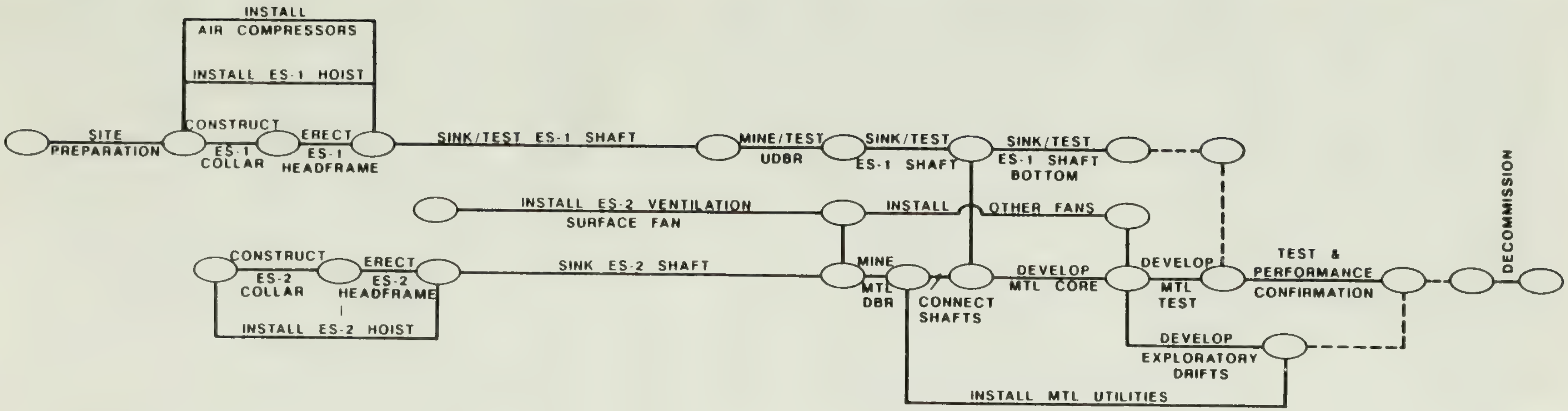



**Figure 8.4.2-31.** Long drift to imbricate normal fault zone. Modified from Title I design package (DOE, 1988).




| | |
|---|---|
| ES | EXPLORATORY SHAFT |
| MTL | MAIN TEST LEVEL |
| UDBR | UPPER DEMONSTRATION BREAKOUT ROOM |

**Figure 8.4.2-32.** Yucca Mountain Project summary logic diagram of exploratory shaft facility.

The site preparation begins by removing top soil and shrubs and initiating earth-moving work for foundations and pads to support the facilities and infrastructure. Various slabs and foundations are constructed, followed by the installation or construction of air compressors, the ES-1 hoist, the ES-1 collar, and the ES-1 headframe. Work at the ES-1 is started first so that testing in the shaft concurrent with ES-1 sinking phase can be begun as early as possible. The ES-1 sinking phase will accommodate geologic mapping and all other shaft site characterization tests, including radial borehole tests, convergence monitoring, upper demonstration breakout room test, vertical seismic monitoring and obtaining samples for laboratory testing. Construction water will be tagged with tracers. In addition, perched-water tests will be conducted if perched water is intersected. Sinking of the ES-1 shaft will be relatively slow because its construction schedule is controlled by the testing requirements.

The ES-2 collar and headframe construction will be started after the ES-1 collar is completed. Construction of the ES-2 collar, headframe, and hoist will be followed by the sinking phase of the ES-2 at a rate that will reach the main test level about 1,055 ft below the collar ahead of the ES-1. The ES-2 shaft construction will also include the surface ventilation fans that will support the initial development drifts of the main test level before the ES-2 and ES-1 shafts are connected. Construction water will be tagged with tracers. If perched water is encountered in ES-2, testing to characterize this water will be conducted in the ES-2. As discussed in Section 8.4.2.3.1, some geologic mapping is planned during construction of the ES-2.

Additionally, the multipurpose boreholes would provide data to support shaft sinking and evaluation of construction impacts related to water usage.

The ES-1 construction proceeds with various tests being performed at predesignated locations as shown on Figure 8.4.2-27.

Other than the initial shaft breakout done during shaft sinking, the first development on the main test level (MTL) level will be the construction and testing of the lower demonstration breakout room. In addition to this, ES-1 and ES-2 will be connected as soon as feasible on the MTL to provide the two emergency egresses to the subsurface activities. The connection of the two shafts will be followed by the development in the dedicated test area to include the excavation and construction of the electrical substation, water pump station, integrated data system, equipment maintenance and science shops, refuge chamber, access loops, and other spaces as identified.

Next, the excavation of the experiment drifts in the dedicated test area and the exploratory drifts is done concurrently after the utilities and the required ventilation fans are installed.

The experiment drifts in the dedicated test area are developed starting with the sequential drift mining tests, waste package test, diffusion test, infiltration test, canister-scale heater test, heated block test, and excavation effects tests. Other tests such as plate jacking test, in situ stress measurement, etc. are performed at various suitable locations within the ESF.

The details of constructing the site pad, ESF surface facilities and utilities; a description of ES-1 and ES-2 collar construction; and a description of ESF underground construction and operations are discussed in the following sections.

#### 8.4.2.3.4.1 Site pad

The ESF surface pad will be constructed using standard cut and fill methods. It is planned that the solid rock hillside will require controlled blasting to develop the necessary cut area, and the resulting rubble will be used for fill to build up the pad downslope. Any additional fill material will be brought to the pad from designated borrow areas nearby (Figure 8.4.2-23). The pad is roughly rectangular, 700 ft long and 480 ft wide, and the pad is oriented slightly east-northeast in major dimension (Figure 8.4.2-24).

The pad surface is designed to slope away from the shaft collars for runoff control (Figure 8.4.2-24). The pad and shaft collars are north of the Coyote Wash channel and above it, outside the reach of any projected flooding potential. Sheet runoff from the hillslope on the north will be channeled away from the pad via a ditch along the north and west perimeter. All the access roads to and from the ESF site are designed with appropriate grade elevations, berms, and/or culverts to handle normal expected runoff and not restrict water flow under conditions of a major flood event. The design bases that have been used are described in the subsystem design requirements document for the ESF (DOE, 1987b).

#### 8.4.2.3.4.2 Exploratory shaft facility surface facilities and utilities

Once the main pad and other associated pads and roads are completed, the shaft collars, mine plant, support buildings, and utilities will be constructed or installed.

#### 8.4.2.3.4.3 ES-1 and ES-2 collar construction

The shaft collars will be constructed by first excavating a square foundation approximately 30 ft, to a depth of approximately 9 ft below the finish grade (10 ft below the finished collar floor elevation). At the center of this excavation, a subfoundation of approximately 24 ft in diameter and approximately 6 ft deep will be excavated, resulting in a total excavation depth of 16 ft below finished collar elevation. Should ground support be required at this depth, a liner plate with ring beams will be placed and grouted; once the foundation excavation is stabilized, the isolation joint excavation of approximately 17 ft diameter by 4 ft deep can take place. The isolation joint will provide a structural discontinuity between the collar/headframe and the shaft liner. A liner plate approximately 16 ft in diameter, and 4 ft deep, with ring beam stiffeners, will be centered on the future shaft. Cement grout will be placed in the bottom 1 ft of the annulus

between the excavation and the plate to hold the liner plate in place. The remaining 3 ft will be filled with gravel to complete the isolation joint. Once the joint is completed, forms can be installed for the vertical shaft penetration, through the collar structure and the horizontal intersection of the utility tunnel. Reinforcing steel, embedded items, and any required bulkheads or blockouts are placed and secured and the collar structure can be completed in a continuous pour (Figure 8.4.2-25).

### 8.4.2.3.4.4 Exploratory shaft facility underground construction and operations

This section describes the various steps in constructing the ES-1.

The ES-1 shaft will provide access to stations at two levels: the upper demonstration breakout room level, and the main test level (Figure 8.4.2-33). The completed shaft will be equipped with the necessary internal structures, conduits, piping, ventilation ducts, ladderway and conveyance to move people and materials in and out of the underground facilities and to support the mining and testing activities (Figure 8.4.2-28).

Construction of ES-1 to the Upper Demonstration Breakout Room

After the collar structure has been completed, but before headframe construction, the shaft will be sunk to a depth of approximately 80 ft. This will allow the sinking stage (Figure 8.4.2-34) to be installed and suspended high enough above the shaft bottom to be protected from blast damage. The headframe and collar doors can then be installed, along with the main hoist, auxiliary hoists, and associated equipment. The sinking stage is a four level, movable assembly of platforms to be used by the shaft sinking contractor during shaft excavation and concrete liner placement. Test personnel will also use the main stage for mapping, and the detachable top deck for monitoring of ESF test instrumentation throughout the shaft during the sinking process. The top deck, being detachable, will provide a safe guided means of test access in all shaft sections and is fully stabilized to prevent tipping. The suspension ropes for the stage will serve as guide ropes for the sinking bucket crosshead. The shaft sinking operation will be repetitive (except for testing) down to the upper demonstration breakout room (UDBR) level.

Vital to the sequence of construction will be the drilling of an advance probe hole in the center of the shaft section. The probe hole will be cored, and will extend to a depth of approximately 200 ft. The primary purpose of this probe hole is to provide immediate and advance information to the sinking contractor, A/E, and principal investigators with regard to perched water and ground conditions. The data obtained therefrom will be correlated with multiple-point borehole extensometers information, and will confirm design adequacy of high quality assurance level items before in situ conditions are disrupted by shaft excavation. Design items to be controlled by this data include temporary support, shaft lining, controlled drilling and blasting, and the proper characterization of encountered perched water before

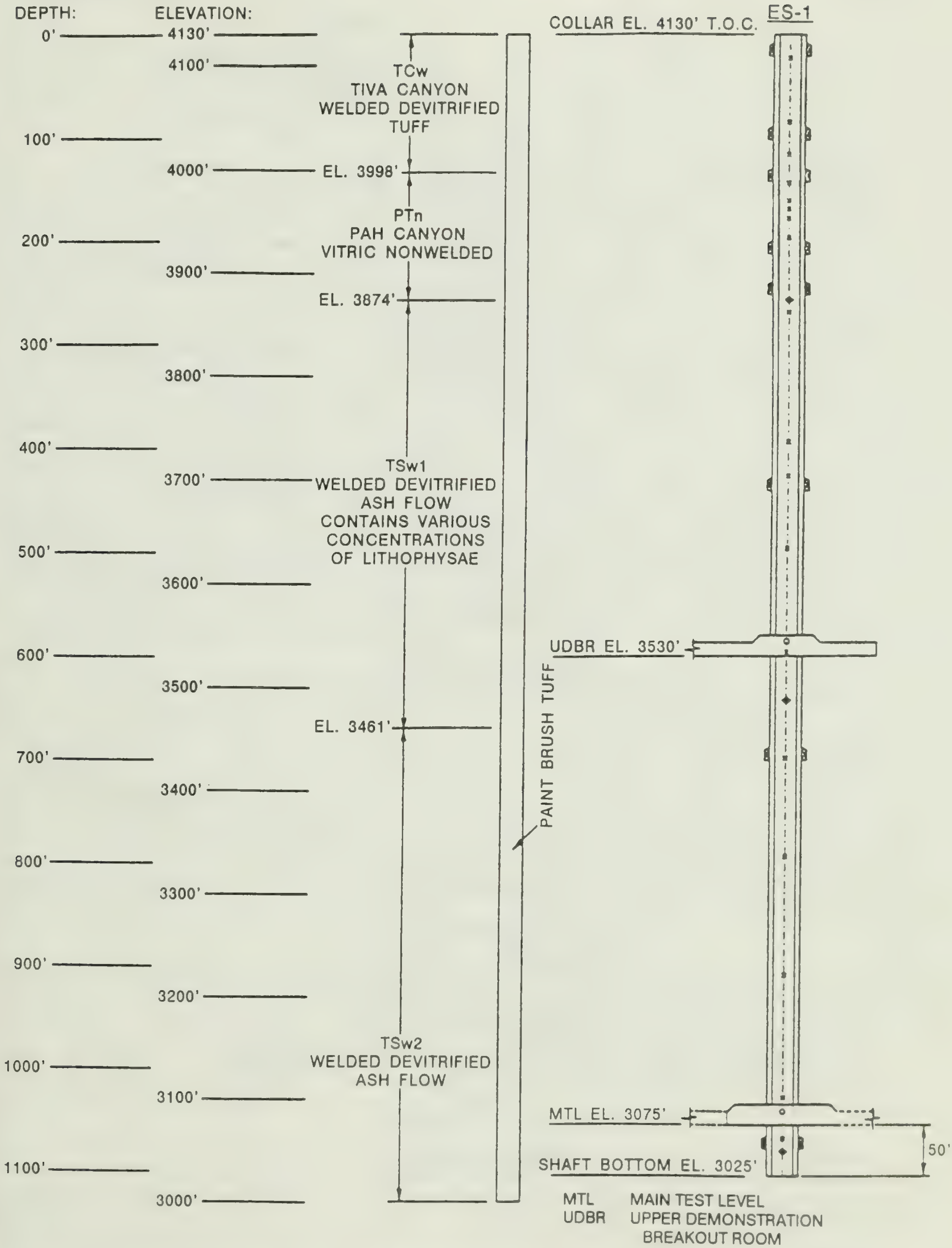
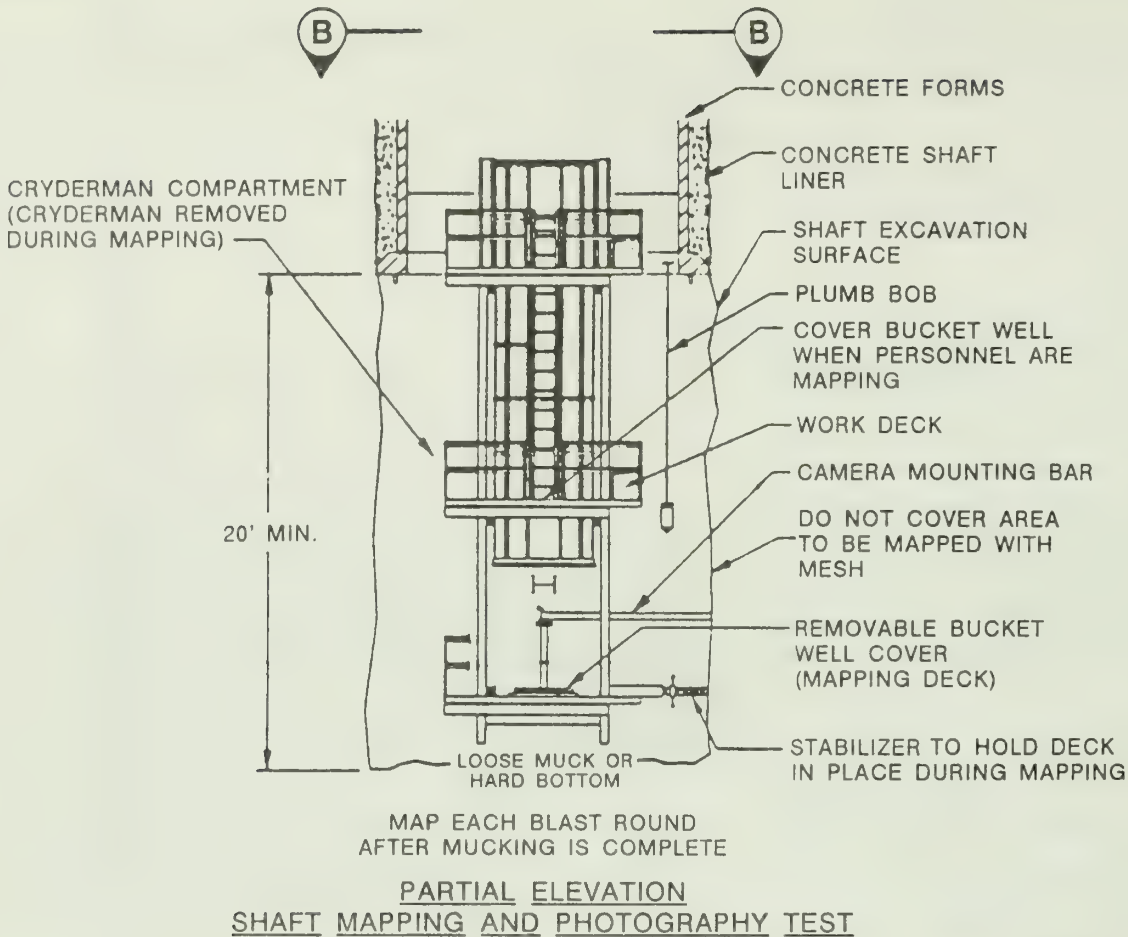



**Figure 8.4.2-33.** Exploratory shaft 1 section illustrating shaft stations. Modified from Title I design package (DOE, 1988).



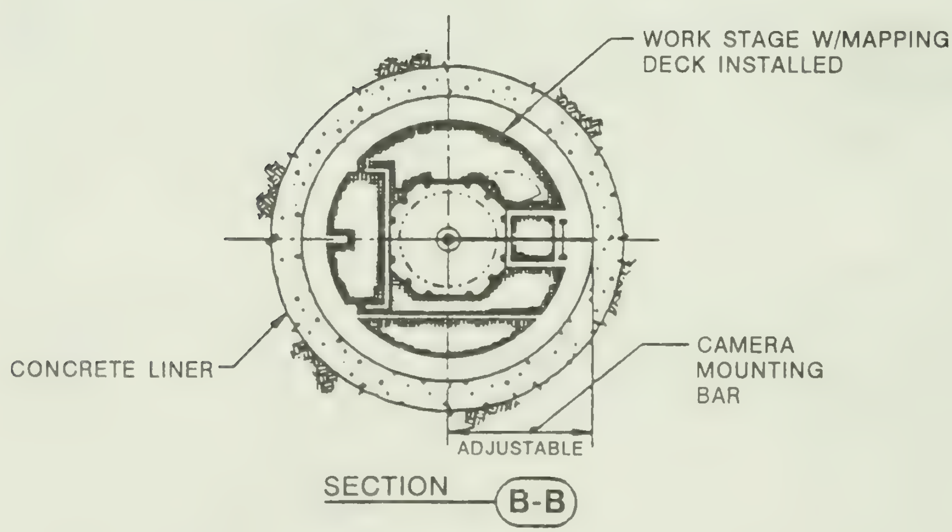




**Figure 8.4.2-34.** Plan and section of sinking deck . Modified from Title I design package (DOE, 1988).

alteration by the shaft sinking process. The probe hole will be advanced as necessary to maintain an adequate depth ahead of the shaft bottom. At completion of the hole, it will be plugged to prevent fluids from entering the hole.

A typical sequence of operations will begin by drilling a number of short, small-diameter holes into the rock at the shaft bottom. The number, depth, location, spatial orientation, explosive charge, and firing sequence for each hole will be designed to meet the requirements of controlled drilling and blasting to minimize change in rock mass permeability (Case and Kelsall, 1987) and to minimize damage to the wall rock. The blast hole design must also provide for efficient vertical advance, as well as acceptable size rock fragments. Procedures to control wall rock-blast damage are being tested in advance and will be completed and approved before ESF construction begins. As excavation advances, blast round design will be adjusted to meet changing conditions of the rock. Table 8.4.2-15 presents case histories of blast damage measured in tunnels. Case and Kelsall (1987) have evaluated the changes in permeability and extent of rock damage in welded tuff. They indicate that the changes in rock mass permeability and blast damage can be estimated from fracture frequency within the blast-damaged zone. By using controlled drilling and blasting techniques, the increase in fracture frequency can be controlled to within 18 in. (0.5 m) of the wall surface. As an upper bound, the increase in fracture frequency is expected to occur to within 3.3 ft (1.0 m) of the wall. Figure 8.4.2-35 provides a method for estimating the thickness of the blast-damaged zone in relation to the explosive charge density.

Several specific blasting techniques fall under the term controlled blasting: line drilling, cushion blasting, presplitting, and smooth blasting. The first two methods are specialized and have limited practical use underground. Presplitting, also called preshearing, involves detonating a lightly loaded charge in closely spaced perimeter holes before the adjacent interior area is excavated by blasting. When executed properly, presplitting creates a fracture plane between the holes that limits the subsequent transfer of energy to the final shaft or drift wall. Smooth blasting, also called contour blasting, is similar to presplitting except that the perimeter holes are detonated after the main blast, breaking free a relatively thin slab of rock creating the final free face.

For both of these methods, the linear charge concentration in the perimeter holes is relatively small compared with fully loaded conventional blastholes. The resultant shock waves from adjacent perimeter holes cause localized stress concentrations in the rock and at the blasthole surfaces, and influence the direction and magnitude of a propagating fracture plane. The end result is a plane of weakness between holes that outlines and limits the extent of the blast activity.

Regardless of the techniques used, the results of any blast excavation primarily depend on the characteristics of the rock encountered. Although controlled blasting works well in some formations, in others it does not work at all. Trial and error in the host rock itself is the method normally used to determine a practical controlled blast design. When successfully executed, the remainder of perimeter blastholes (half-hole casts) can be seen about the contour of the opening.

Table 8.4.2-15. Case histories of blast damage measured in tunnels[a] (page 1 of 2)

| Site | Rock type | Blasting method | Tunnel dimension | Depth of damage | Measurement method | Comments | Reference |
|---|---|---|---|---|---|---|---|
| Colorado School of Mines (Edgar Mine), Colorado | Biotite gneiss | Smoothwall | 5 m x 3 m | 0.5 m | Borehole loggings, cross-hole permeability (packer tests), bore-hole deformation | Depth of blast damage not well documented but in agreement with theoretical calculations | Montazer and Hustrulid (1983) |
| Stripa mine, Sweden | Granite | Smoothwall | 4 m x 4 m | 0.3 m | Boreholes | Fracture lengths ranged from 0.1 to 0.1 m, with an average length of 0.3 m; permeability of blast damaged zone not measured | Anderson and Halen (1978) |
| Rainier Mesa, Nevada Test Site | Zeolitized tuff | Conventional | 3 m | <1.7 m (?) | Air permeability | Blast damage not well distinguished from stress effects | Miller et al. (1974) |
| Rolla Experimental Mine | Dolomite | Various | 2.5 m x 2.2 m | 0.3 to 2.5 m | Seismic refraction | Depth of damage varies according to method of blasting used; blast damage not distinguished from stress relief | Worsey (1985) |
| Test drift | Basalt | Conventional | 5 m | ~ 2 m | Cross-hole seismic | Blast damage seen most clearly in vertical travel direction in drift wall, effects of stress relief seen in horizontal direction | King et al. (1984) |
| Ontario, Canada | Limestone | Presplitting | ~8 m | ~1 m | TV camera in boreholes in crown | Separate zones of moderate cracking and hairline cracks; depth of damage varies with charge weight | Lukajic (1982) |
| Saimogo, Japan | Sandstone/ shale | Conventional | 5.1 m | < 1.3 m | Seismic refraction | Comparison of blasting with excavation by tunnel boring machine; difficult to separate blast damage from stress relief | Nishida et al. (1982) |

Table 8.4.2-15. Case histories of blast damage measured in tunnels[a] (page 2 of 2)

| Site | Rock type | Blasting method | Tunnel dimension | Depth of damage | Measurement method | Comments | Reference |
|---|---|---|---|---|---|---|---|
| Crestmore Mine | Marble | Conventional | 30 to 70 ft | 4 to 5 ft | Seismic refraction borehole jack, borehole logging | The borehole jacking method was used to determine the rock mass deformation modulus | Heuze and Goodman (1974) |
| Churchill Falls, Canada | Gneiss | Controlled perimeter | 2.1 m x 2.4 m | <1 m | Plate load test | Most damage within 0.3 m | Benson et al. (1970) |
| Straight Creek, Colorado | Granite/ gneiss/ schist | Conventional | 4 m | "few ft" | Seismic refraction | Blast damage depth estimated within overall low velocity layer extending 1 m to 5 m | Scott et al. (1968) |
| Belledonne, France | Granite | Conventional | 5.9 m | ~1 m | Seismic refraction | Blasting and stress relief effects not specifically distinguished | Plichon (1980) |
| Mine | Shale | Conventional | NA[b] | 0.5 to 1 m | Seismic refraction | Blasting and stress relief effects not specifically distinguished | Brizzolari (1981) |
| Rama Tunnel, Yugoslavia | Dolomite | Conventional | 5 m | <1 m | Cross-hole seismic | Blasting and stress relief effects not specifically distinguished | Kujundic et al. (1970) |
| Turlough Hill, Ireland | Granite | Conventional | 2.5 m | 0.5 to 2.5 m | Cross-hole seismic | Blasting and stress relief effects not specifically distinguished | O'Donoghue and O'Flaherty (1974) |

[a]Source: Case and Kelsall (1987).
[b]NA = not available.

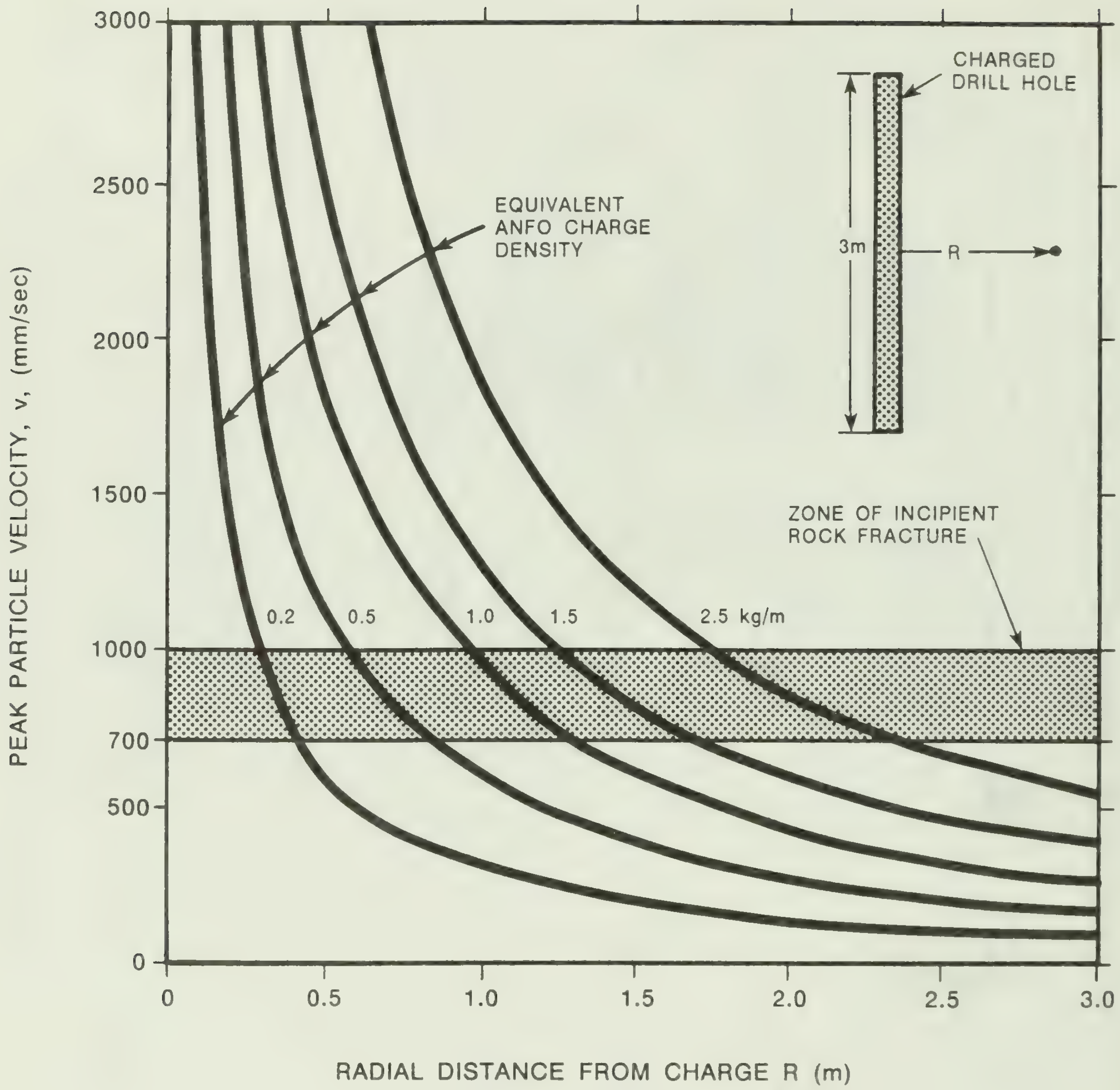



**Figure 8.4.2-35.** Method for estimating the thickness of the blast-damaged zone in relation to explosive charge density. Modified from Case and Kelsali (1987)

Of the four techniques of controlled blasting, cushion blasting, line drilling, presplitting, and smooth wall blasting, the method considered most suitable to the Yucca Mountain Project is smooth blasting. Cushion blasting requires holes that are too large in diameter to be used underground. Also, it cannot be used in other than vertical holes. Line drilling has extreme alignment tolerances and is not practical for rounds more than a couple of feet deep. Presplitting requires drilling, loading, and firing the perimeter holes as a separate operation, before the interior holes are drilled, loaded, and fired. The possibility of having undetonated explosives in the presplit holes makes this method more hazardous in an underground operation where close hole spacing is required. Smooth wall blasting is the recommended method for Yucca Mountain because

1. Conventional underground equipment can be used.

2. Reasonable round depths (6 to 12 ft) can be maintained.

3. No unusual safety hazards will be introduced.

4. Rock damage outside the excavation perimeter can be confined to reasonable limits.

There are six factors that influence the performance of any blasting technique, including smooth wall blasting. These factors are geology and rock characteristics, drill precision, blast-pattern layout, charge concentration, acoustical coupling, and detonation and sequencing. When using the smooth wall blasting technique at Yucca Mountain, adjustments in the blast round designs will be made to compensate for changing geologic conditions and blast results.

Prior to blast-round detonation, the sinking deck and associated equipment will be raised to a safe distance above the blast to protect them from damage. The miners will then exit the shaft, and the explosives will be detonated. Following each blast, the ventilation system will remove smoke, dust, and fumes before the miners enter the shaft to muck out the rubble.

After smoke, dust, and fumes are vented, the miners will re-enter the shaft, reposition the work deck, lower the mucking machine, and bar down any loose rock from the shaft walls. Scientists can then collect rock samples from the muck pile, assisted by the miners. The muck will be loaded into a sinking bucket and hoisted to the surface by the main hoist in repetitive cycles until the shaft bottom is cleaned out. Geologic mapping of the exploratory shaft will take place immediately after each round of excavation is completed and after the new wall exposures are cleaned and surveyed. Other testing will be conducted at selected elevations on greater intervals, which will require more extensive set up. The primary purpose of ES-1 is to provide access for scientific investigations; therefore, time will be provided to successfully accomplish the mapping, sampling, or other testing objectives using approved methods and procedures that are as efficient as reasonably possible. These testing activities are described briefly in Section 8.4.2.3.1.

When the scientists have completed their work, the miners will prepare the next blasting round. After several blasting rounds, the shaft-liner

concrete will typically be placed (poured) in 20-ft segments. Conventional mining practice allows lining of a shaft all the way to the working face (Cummins and Given, 1973). However, to ensure that the freshly-poured or "green" concrete is not damaged by continuing construction activities (drilling, blasting, and mucking) at the working face of the shaft, a 20-ft-minimum standoff distance will be maintained between the bottom of the shaft liner and the working face of the shaft. Where specified by scientists, blockouts will be installed in the liner to protect extensometer anchors, drill collars, etc., before the liner is poured. The unreinforced concrete liner is specified to be at least 1 ft thick through the welded tuff units. The sequence of activities will be repeated down to the proposed depth of the UDBR. At selected depths, sinking will be delayed while radial-borehole, shaft-convergence, perched-water (if found), or other tests are conducted.

For various reasons, general mining activities require the use of small amounts of water. For the ESF, however, every effort will be made to limit the amount of water used to the minimum required.

When drilling blast holes, small amounts of water must be circulated through the drill steel and out the hole to flush the cuttings. This action not only suppresses the dust created by the drilling action, but also serves to cool the drill bit. Water used in this fashion will be controlled by adjusting the water flow through each drill to the minimum required to prevent dusting. Water will also be kept turned off at any time the drill is not actually drilling.

Another use of water will be to suppress dust and fumes during and after a blast. This is done by creating a mist formed by compressed air into which a small stream of water is injected. Misting will take place before loading, hauling, dumping, and hoisting, since the broken rock must be wet down enough to prevent dust during the handling process. Special geologic mapping requirements and bulk sampling techniques may require more or less water to be used based on individual testing program needs.

All construction water that does not get absorbed and removed in the rubble will be collected by pumps located at both the shaft bottom and drift face. This water is then transferred to the main wastewater disposal system for pumping to the surface. All water introduced into the ESF, other than naturally occurring ground water, will be tagged with nontoxic chemical tracers to distinguish it from the ground water. A water balance of water piped into the facility and water removed will be maintained at the shaft collars. Excessive, uncontrolled use of water underground will be prohibited.

Approximately 28 ft above the selected breakout depth, a hitch will be excavated around the shaft wall to form a bearing ring hitch. The shaft wall rock will be reinforced with rock bolts and reinforcing steel embedded in the concrete from this bearing hitch to the station breakout. The purpose of the reinforcement is to remove heavy vertical loading on the wall rock at the breakout level so that mining of the UDBR can proceed safely and with ensured long-term stability of the drift opening near the shaft.

## Construction of the upper demonstration breakout room and station

The rationale for the location of the upper demonstration breakout room (UDBR) is to characterize rock having approximately 15 percent lithophysal void content that may be encountered at places in the proposed repository horizon. This information will help site-modeling efforts to predict the thermal and mechanical response within lithophysal-rich zones of the proposed repository horizon. In addition, the constructibility and stability of the drifts will be established for lithophysal rock conditions. Work on the UDBR will actually include mining two types of rooms: (1) the station excavated directly off the exploratory shaft and (2) the UDBR excavated off the station (Figure 8.4.2-36).

The station will provide a reinforced area for off-loading equipment and handling muck produced by UDBR construction. The station will be reinforced with rock bolts, wire mesh, steel sets, and lagging. Fractures and other features exposed in the walls and roof of the station will be mapped during construction.

The UDBR excavation will be accomplished by drilling rounds of small-diameter shot holes about 7 ft into the face, loading them with explosives, and blasting. The hole patterns, explosive loads, and detonation timing will all be designed to enhance the advance, reduce blast damage to the drift walls, and produce acceptable-size rock fragments. Following each blasting round, the drift will be ventilated to remove smoke, dust, and fumes before the miners reenter the drift to muck the rubble. The muck will be transported to the shaft and loaded directly into the muck bucket for removal to the surface.

After the newly excavated drift space is cleaned out and made safe for entry, the scientists will map the fresh surface exposures. Some of the geomechanical tests will begin concurrently with UDBR mining so that the initial response of the rock mass can be measured. Instrumentation used for the tests scheduled for the UDBR tests will be wired into the integrated data system located on the surface. Data collection and analysis can, therefore, begin immediately and will continue while the shaft is mined to its total depth. Stress and permeability test holes will be drilled and data instrumentation installed in the UDBR before shaft sinking resumes.

After the tests described in the previous section have been established and are producing data, the shaft sinking will resume until the main test level is reached. The same construction and testing sequence described previously will be used. In addition to the regular mapping and sampling activities, shaft-sinking operations will be interrupted periodically for drilling, testing, and instrumentation of test holes.

## Construction of the main test level station

At approximately 28 ft above the main test level, a reinforced brow liner will be constructed to reinforce the main test level station. This station will be constructed in essentially the same manner as the UDBR station. Station breakout drifting will be extended far enough away from the ES-1 shaft such that blasts from the connecting drift from ES-2 will not damage ES-1 or its station.

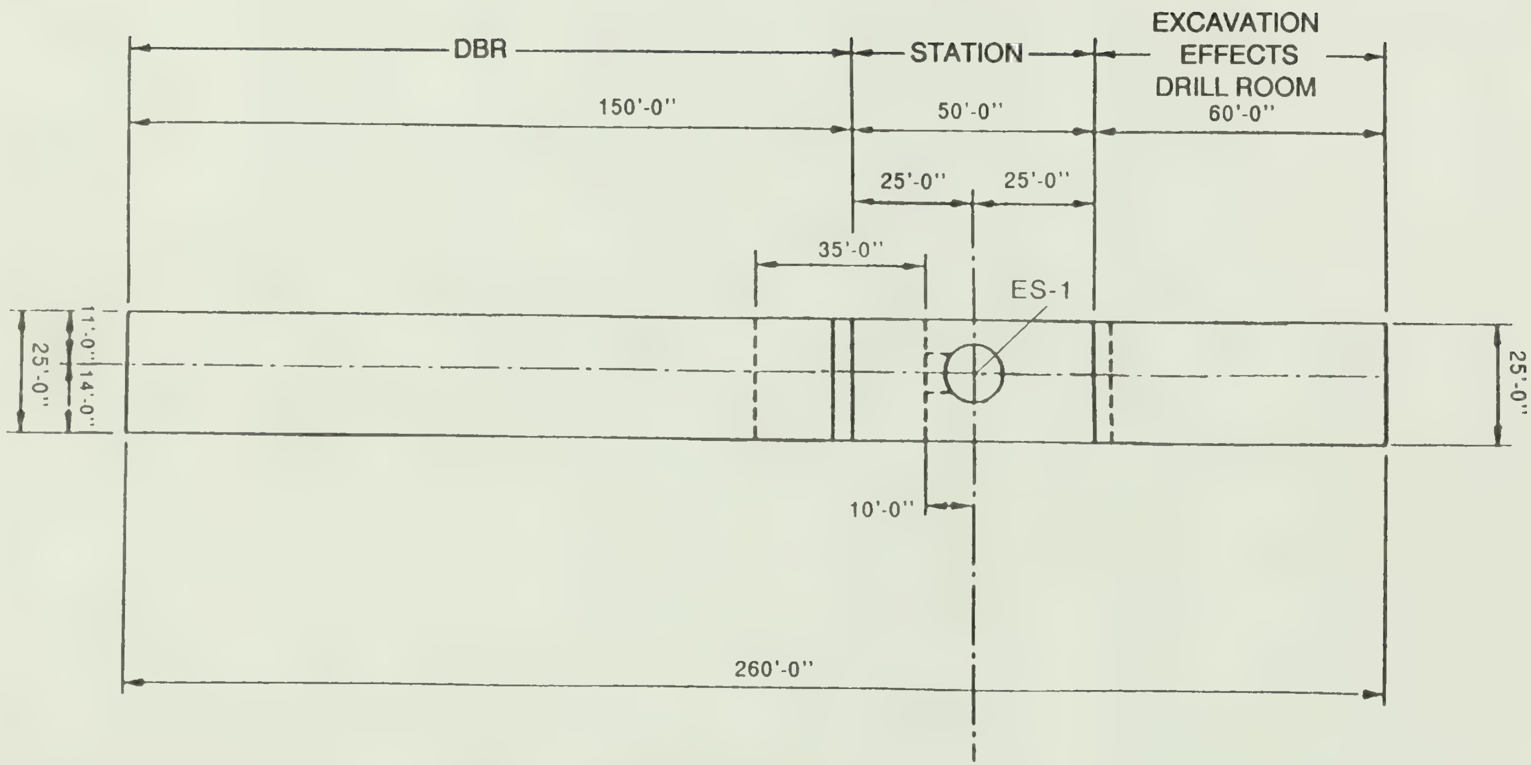



**Figure 8.4.2-36.** Upper demonstration breakout room showing stations of the exploratory shaft.

Below the main test level, ES-1 will continue to be sunk, mapped, and lined in the manner just described. When shaft sinking, lining, and testing are completed to total depth, equipment such as steel buntons to support conveyance guides, the conveyance, an enclosed ladderway, pipe lines, electrical cables, ventilation ducting, and communications systems will be installed (Figure 8.4.2-28). Steel anchor inserts in concrete lining will be provided for attaching the above items, and no new drilling in the lining will be performed. This will eliminate disturbance to testing in the shaft.

At the shaft bottom, a sump pump will be excavated and pumps installed for water removal. Water is not expected in the underground facilities, but small amounts of water could be released to the underground facilities during construction and testing from perched-water zones, percolation seepages, water used for dust control at working headings, or waterline accidents. If a seep or perched-water zone is encountered, some water will be collected for analysis and any excess water will be pumped to the surface and discharged in the mine waste-water pond. The quantity of water removed from the shafts will be measured and recorded. The details and capacities of the waste-water removal system are provided in the Title I design.

Construction of ES-2

This section describes ES-2 and the various steps in its construction. ES-2 will be used for secondary emergency egress from the facility, for transport of people and materials, for muck removal, and for additional ventilation capacity for the long exploratory drifts. A connecting drift to ES-1 and a demonstration breakout room (DBR) will also be constructed from ES-2 on the main test level after ES-2 is completed. Short delays for mapping and photography are planned while mining ES-2. As described in Sections 8.3.1.2.2.4.7 and 8.4.2.3.1, testing related to perched-water zones will be done in ES-2 if such zones are encountered during ES-2 construction.

ES-2 is also a 12-ft finished diameter, concrete-lined vertical shaft extending from a level pad at the same elevation as ES-1 to just below the main test level. The completed shaft will include the internal fittings, ventilation duct and plenum area, and conveyance guides and compartments shown in Figure 8.4.2-29. At the main test level, a station, muck pocket, and equipment staging area will be constructed. A drift for the DBR geomechanics tests at the main test level will be constructed off of the ES-2 landing/staging area (Figure 8.4.2-30). The connecting drift to ES-1, located 300 ft west-southwest will be mined from ES-2 in time to complete the connection as soon as ES-1 reaches the main test level. When the two shafts are connected, ES-2 will be used to support mining of the test areas and exploratory drifts.

Construction of ES-2 to total depth

The current plan is to construct ES-2 using drill, blast, muck and lining methods similar to those used for ES-1. The shaft internal fittings, as in ES-1, will be installed after the shaft is sunk and lined to its total depth. There will be regular interruptions for shaft wall mapping after each few rounds of blasting and mucking and before the liner is being placed. Shaft construction will be also delayed for testing of perched water or

anomalous geologic structures if encountered, or if otherwise deemed necessary by the project.

Construction of ES-2 station and the connecting drift to ES-1

The construction of the ES-2 station at the main test level will be essentially the same as that for the ES-1 main test level station. A reinforced brow liner will be constructed by excavating a bearing hitch, rock bolting the wall rock, and reinforcing the concrete liner above the station breakout, as described for ES-1. An additional feature at this breakout level will be the construction of a muck pocket and chute adjacent to, but outside, the shaft diameter. The chute will discharge stored muck directly into the skip in the shaft. After the station and equipment staging areas have been completed, the main test level DBR will be excavated and tested, and a drift that will connect ES-2 with ES-1 will be mined by the drill, blast, and muck technique. If ES-1 has not reached the main test level, the connecting drift will be stopped before it reaches the ES-1 intercept point so that the connection can be made after completion of the ES-1 station. More detailed design information about the ES-2 station and the connecting drift will be presented in Title I design report.

Construction of the main test level demonstration breakout room

Like the UDBR (off ES-1), the main test level DBR (off the ES-2 landing) will be mined to obtain rock mechanics data related to mining methods and constructibility in welded tuff. The mining and testing methods will be the same as for the UDBR. When the main test level DBR testing is completed, the drift space will be available for other testing or mining operations uses. The main test level DBR tests are planned to be performed from ES-2 before extensive drifting operations are started because they will provide engineering data useful for mining the main test level operations area.

Construction of the main test level and main test level operations level

The main test level (MTL) will be mined by conventional drill, blast, and muck methods. The same technique of controlled drilling and blasting that was described earlier for the construction of ES-1 to the UDBR will be applied through the MTL. These operations consist of drilling many small-diameter blast holes in the drift face, loading them with explosives, and timing the charges to produce a sequential, controlled blast that will meet the design specifications. The resulting rock rubble will be loaded and transported to the shaft muck pocket and then transported to the surface in the skip. Mechanical mining, a postulated technique for use in repository construction, will not be used for ESF drift construction because it is not economically justified given the limited amount of excavation to be done.

After blasting and muck removal and after ensuring safe conditions, the freshly exposed rock will be mapped and photographed and then reinforced as required with rock bolts, wire mesh, and shotcrete before preparations are started for the next blast round.

The actual sequence of mining the drifts is still under consideration and will be developed in coordination with testers, but the connecting drift between ES-1 and ES-2 is a high-priority activity for reasons of safety.

Because the ES-2 operations shaft is expected to reach the main test level several weeks before ES-1, drift space for equipment and material staging and a drift for the main test level DBR tests are planned to be completed first. Then the connecting drift will be constructed in time to effect the connection when ES-1 reaches the main test level.

When ES-1 and ES-2 are connected, the balance of the main test level operations area drifts will be mined, followed by the individual test alcoves and drifts (Figure 8.4.2-30). Mining of the long exploratory drifts may be started while mining of the various test drifts and alcoves is taking place, or may begin about the time the test facilities are completed. Operational and testing constraints will be a determining factor in scheduling the drift mining activities.

The design of the main test level operations area has been developed to meet several objectives. A primary design objective is to provide maximum flexibility within the area of the proposed repository horizon set aside for exploratory shaft testing. The concept consists of having a dedicated testing area (Figures 8.4.2-4 and 8.4.2-30) that takes into account test constraints described in the SDRD (DOE, 1987b) and in Section 8.4.2.3.1.

A second objective is to ensure that the main test level operations area design will be compatible with the design of a repository. In this regard, the drifts are designed to minimize constraints on future repository uses such as ventilation or other repository operations.

A third objective is to ensure that the proposed drifts to the boundary structures to the north and east and to Ghost Dance fault to the west will not compromise site integrity and will not jeopardize future repository emplacement space. This objective will be accomplished by locating the exploratory drifts along the alignments of the current conceptual layout of the repository drifts, by establishing construction procedures for water control, including for unexpected quantities, and by adapting rock support to changing and potentially poor conditions.

Probe holes will be drilled ahead of each drill face to a minimum depth of twice the depth of the blast round as conditions warrant in areas where faulting or disturbed zones are expected. The determination to drill probe holes will be a function of previous experience in the drifts, expected conditions and professional judgment. If appropriate, a series of probe holes will be drilled that penetrate to the left and right, as well as above and below the drift face. Probe holes will first be collared in 2 to 3 ft at a larger diameter than the planned probe hole. A drill-through mechanical packer with full-opening valve will be installed if water is expected. The remainder of the probe hole will be drilled through the packer and valve assembly such that if water is encountered, the drill steel and bit can be withdrawn and the valve shut to contain the water. The packer and valve assembly will have a threaded outlet so that meters, gages, and piping can be attached. If water is encountered in the probe holes, present designs for the ESF include sufficient pumping capacity to remove water from the ESF to the surface. Should probe hole drilling indicate adverse ground conditions, present mining plans include the flexibility required to adapt ground control techniques and support components to a wide range of conditions to ensure long-term drift stability.

A fourth objective is to provide a centrally located data acquisition system, convenient to the test areas and shafts but adequately isolated from the mining operations.

A fifth objective is to provide a sufficient operations, capability, and dedicated area to accommodate later performance confirmation tests from the same facility.

Other objectives relate to operational and safety considerations such as traffic flow, equipment maintenance, shop space, suitably located refuge chambers, ventilation, and underground utility requirements. The main test level area incorporates all these factors into its design and should, therefore, be operationally efficient, safe, and very flexible in supporting the testing effort.

The main test level drifts used for hauling muck and to support mining activities will provide access to both shafts; access to and between the test areas, space for equipment maintenance, shops, and space for suitably located refuge chambers. Space is also assigned for the integrated data system with an uninterrupted power supply and work stations for the investigators. The drifts in the main test level operations area will be sized to allow two-way traffic plus all utility lines, wire racks, and ventilation ducts. The drifts will be reinforced with rock bolts, wire mesh, and shotcrete, as required, based on rock conditions encountered.

Construction of exploratory drifts

Exploratory drifts are planned to gain access to three specific features within the proposed repository block: (1) the Ghost Dance fault, (2) the Drill Hole Wash structure, and (3) the imbricate normal fault zone to the east. The locations of the three drifts are shown in Figure 8.4.2-4. The lengths of the drifts have been estimated based on projections of the fault planes from the surface to the intercept elevations. The uncertainty in the length estimates is about 200 ft for each of the three drifts. The drifts could be slightly shorter than the estimates provided in the following sections if the intercept locations occur as projected.

Each drift will be mined using the same techniques as for the main test level operations area described earlier. The walls and the roof will be rock bolted and covered with wire mesh as required. Mapping and geomechanics tests will be conducted during the mining of the drifts and across the target geologic structures. Any unforeseen, anomalous features encountered while mining these drifts will be considered for additional study.

Drift to the Ghost Dance fault

The drift to the Ghost Dance fault will examine features potentially important to the design and performance of a repository. First, the fault is a potential transmissive zone for water from the surface to the water table. The drift will allow direct observation, collection of samples, and measurements needed to model the hydrologic environment. Other information that can be obtained by this drifting pertains to the nature of the fault zone including information on the time of last movement, and the magnitude and direction of fault offset.

To reach the Ghost Dance fault area, a drift approximately 2,050 ft long, heading northwest from the main test level operations area, will be constructed by using the controlled drill, blast, and muck technique previously described.

Drift to the Drill Hole Wash structure

The drift to the Drill Hole Wash structure will examine characteristics potentially important to the construction and performance of the repository. Structural features, such as faulting, that have been postulated based on surface mapping and drill holes will be examined. If the investigation shows little or no faulting, then the area north of Drill Hole Wash might be shown to have potential for repository use, should contingency emplacement space be needed sometime in the future.

The hydrologic character of the rock structures below Drill Hole Wash will also be studied from this drift. Because the wash tends to concentrate surface waters and channel them along a specific path, higher than average infiltration rates could occur in this area. Studying this area may resolve concerns about seasonal change and movement of water down fracture zones. To reach the Drill Hole Wash structure area, a drift approximately 2,170 ft long heading northwest and the northeast from the main test level operations area will be constructed by using the drill, blast, and muck technique previously described.

Drift to the imbricate normal fault zone

The drift to the imbricate normal fault zone is planned to study the geometry of the fault zone, the strike and dip of the faults, and the location of these faults at the proposed repository depth. These studies will help determine the eastern boundary of the repository block. Hydrologic studies will also be performed to determine whether this fault zone is transmitting water.

A drift heading southeast from the main test level operations area approximately 1,400 ft long will be constructed by using the controlled drill, blast, and muck technique previously described.

### 8.4.2.3.5 General description of underground support systems

The following subsections describe the ESF underground support systems. These systems, which all relate to the underground mine environment, are mine ventilation, rock support, life safety systems, fire protection, health and safety, and mine evacuation and rescue.

Mine ventilation

The ventilation system will supply and exhaust adequate air quantities of acceptable quality to and from underground working areas, to provide personnel safety, health and productivity in accordance with applicable Federal, State and Local regulations. To support the various phases of the

ESF construction, operation and test characterization, the primary ventilation system is designed using both ES-1 and ES-2 as intake air shafts. Inside each shaft is a structurally reinforced metal duct used as a separate exhaust airway. Primary exhaust fans installed in the surface and underground create the pressure differential which directs the fresh air supply down the shafts and into the various areas of the main test level. Return air exhausts through the metal ducts to the surface. Air-flow rates are controlled so that air quantities are distributed to satisfy the following design criteria:

1. Shaft and drift air velocity shall not exceed 2,000 and 1,500 fpm respectively, to avoid high air velocity hazard.

2. A minimum of 60 fpm air velocity shall be maintained in any active airway to avoid air stagnation or toxic gas accumulation.

3. Presence of diesel equipment requires ventilation of at least 100 cfm per brake horsepower.

4. Personnel shall be provided with ventilation of at least 200 cfm per person.

5. The subsurface environmental temperature shall be maintained to generate a minimum air cooling power of 260 $W/m^2$. This will be attained without using mechanical air cooling and refrigeration since the estimated ambient temperature of the rock at the main test level is below 80°F.

Active drifts away from the primary airways are ventilated by appropriate auxiliary fans and ducting to satisfy the required airflow in the drifts.

The airflow available for the ESF ventilation is about 220,000 to 234,000 cfm at the shaft collar. After allowing for leakages, the effective air quantities are distributed to the following areas:

| Area | Range of air quantity (cfm) |
|---|---|
| Main test level | 60,000-65,000 |
| Imbricate fault drive | 45,000-50,000 |
| Ghost Dance fault and Drill Hole Wash drives | 57,000-66,000 |
| Equipment maintenance shop | 19,000-20,000 |
| Total | 181,000-201,000 |

To attain the desired airflow distribution, subsurface doors, regulators, fans, and other ventilation controls will be provided where needed. Ventilation of a typical development drift will have an air quantity of 45,000 to 50,000 cfm. The air quantity will support the operation of diesel equipment up to a total of 400 brake horsepower in the development drift. An example of typical diesel activity would be two 5-yard loaders (185 broke horsepower each) simultaneously tramming in the drift, or one 5-yard loader

and one 8.8-yard dump truck (129 broke horsepower). Additional utility vehicles may be operated in the same drift to use the remaining capacity of the system up to the 400 brake horsepower limit.

Primary exhaust fans installed in the surface and as underground boosters are operating at pressures ranging from 9.6 to 11.5 in. water gauge with electric motors ranging from 200 to 350 brake horsepower. Primary fans are provided with controls for airflow reversal in case of emergency.

Primary and auxiliary fans will be provided with attenuators to limit the sound pressure level to less than 85 dbs, the 8-hour threshold exposure requirement of the American Conference of Governmental Industrial Hygienists. Shaft stations are provided with fire doors to isolate ES-1 or ES-2 from the main test level in case of fire.

Airborne dust from roadways, muck transfer points, drilling, bolting, and blasting will be controlled and limited to concentrations below the threshold limit values. Dust suppressants consisting of water and biodegradable/nontoxic chemical additives will be applied regularly to subsurface roadways. These dust suppressants are not expected to adversely affect mine waste water discharges. Where applicable, plain water spray or other wetting agents will be used to suppress dust, in amounts consistent with goals to minimize water use to levels required for health and safety. Appropriate stationary or mobile dust collection systems provide the means to further enhance dust control.

A typical dust collection system consists of a series of cyclones and filters that will remove 99 percent of particles greater than 3 micrometers, and 96 percent of particles down to 1 micrometer. Stationary dust collection units will be applicable to permanent muck transfer points such as loading and unloading pockets and dump stations. Mobile dust collection units mounted on wheels will be used during drilling and bolting and after blasting and mucking.

Rock support

Rock support needs are determined using several available methods. These methods include both analytical and empirical approaches, which are supported by historical experience with underground construction. Results of these analyses serve as a basis for developing the flexible systems for reinforcement capable of accommodating various rock conditions anticipated underground.

Ground support requirements for each segment of a drift may vary over relatively short distances, depending on the local geologic conditions. Based on the visual inspection by a qualified professional, the local ground conditions are classified in terms of rock-mass categories. In turn, the rock-mass category is assigned a specific rock-support system, including the procedures and the hardware necessary for its proper implementation. Thus, the rock-support system is adaptable to local conditions.

Depending on the rock-mass class, the rock-support system may include rock bolts, wire mesh, shotcrete, or the combination of those as specified for each system.

Analytical methods

Analytical methods use the analyses of stresses and deformations around openings and include numerical modeling techniques, such as the finite-element method. These methods are very useful in strata control because they enable comparisons of various underground excavation systems and serve as a design process. They are also very useful in forecasting the possible performance of underground openings over extended periods of time, where such aspects as the influence of temperature and/or time-dependent properties of rock (e.g., creep) are to be assessed.

Finite-element codes, such as VISCOT, will be used to evaluate the stability of underground openings. Several studies in which this code was used have been reported in the literature, and the code certification process is currently well under way. Once the certification process is completed, the code will serve as one of the design tools acceptable from the quality assurance point of view.

There are a number of other codes currently available, each appropriate for analysis of certain types of problems. Other code(s) may be used to analyze the stability of underground openings.

Empirical methods

Sophisticated computer analyses inherently incorporate a number of assumptions related to the properties of the rock mass, the state of stress anticipated in a particular underground situation, the geometry of the opening(s), etc. As pointed out by Hoek and Brown (1980), the combined effect of all the factors and processes contributing to the stability of underground openings can seldom be determined. Invariably, the designer is faced with the need to arrive at a number of design decisions in which his engineering judgment and practical experience must play an important part.

To provide a link between the results of analytical studies as well as to incorporate practical experience gained from operations performed under similar underground conditions at other sites, some form of classification system is needed. Such a system allows the results obtained from analytical studies and experience to be translated into a series of engineering drawings, specifications, and procedures leading to a successful implementation of the design concepts.

Hoek and Brown (1980) recommend two common classification methods for use in the preliminary design of underground excavations, namely, the classification of joint rock masses (South African Council for Scientific and Industrial Research) proposed by Bieniawski (1974), and the tunneling quality index (Norwegian Geotechnical Institute) proposed by Barton et al. (1974a).

These two methods will serve as a point of departure for the development of a site-specific rock-mass classification appropriate for the tuff formations at Yucca Mountain. As a result, a set of procedures, along with detailed drawings showing various rock-support systems, will be developed. These will be simple enough to use under field conditions and will contain specific information to help select a suitable rock support system for particular rock conditions encountered underground.

Life safety

The function of the life safety system is to provide systems to alert on-site personnel of danger, ensure a timely response to emergency conditions, provide safe shutdown and evacuation if necessary and limit interruption to the site characterization program.

Life Safety is a broad concept that includes other major system components. Some of these components are

1. Fire protection.
2. Alarm warning system.
3. Emergency communication systems.
4. Evacuation plans.
5. Atmospheric monitoring and control systems.

Each of these systems is engineered separately to maintain its individual integrity. In addition, all systems are designed to function in a coordinated capacity by interfacing shared responsibilities for overall program effectiveness.

Fire protection

The fire protection system is a part of the life safety system. Its development is based on the anticipated fire hazards, and the use and occupancy of each area. The fire protection system will include

1. Automatic extinguishing systems using water sprinklers, halon, and foam.

2. Manual extinguishing systems such as portable dry chemical units, factory-equipped rolling extinguisher systems, fire doors, fire dampers, and ventilation controls.

3. Automatic detection system for smoke and heat (flame).

Each component of the fire protection system is designed considering credible accident scenarios that may be attributed to various ESF functions. Fire protection for these events is part of the total consideration given to safety, and the system interfaces with other life safety systems involved.

Health and safety

The DOE has an established health and safety program. The following policies are followed by the project management:

1. Accident prevention.

2. Safety promotion and training.

3. Supervisors' health and safety inspections and reports.

4. Resolving safety and health complaints.

5. Accident and injury reporting system.

6. Safety awards for outstanding injury and illness prevention achievement.

7. Job safety analysis program.

8. Construction and occupational safety standards.

Evacuation and rescue

The ESF organization has emergency evacuation and rescue procedures developed to respond to fire, flood, and other catastrophic events. These procedures detail the proper response and sequence of action to be taken by subsurface personnel to various emergency calls.

A well-planned and well-rehearsed program of evacuation and rescue for ESF personnel will be followed. Adequate training and drilling of personnel and management in this program will be provided, including these topics:

1. Early warning and alarm systems.
2. Use of self rescuers.
3. Basic ventilation circuitry.
4. Direction to emergency exits.
5. Use of emergency hoist.
6. Use of refuge chambers.
7. Survival techniques.
8. Barricading.

Equipment that is important to life safety is designed with redundancy so that back-up systems are available during an emergency.

A designated person in each shift will be responsible for initially coordinating the emergency response until relieved by the head of the Emergency Coordinating Committee. Initial rescue response such as mobilization of mine rescue team, planning to establish underground fresh air base, and actual rescue and recovery work will be started as soon as possible after an emergency occurs. The head of the Emergency Coordinating Committee may solicit the help from various organizations to carry on the rescue and recovery work.

## 8.4.2.3.6 Evaluation of exploratory shaft facility layout and operations

This section evaluates the ESF layout and operations with respect to interferences that could affect the experimental program, coordination with the geologic repository operations area design as required in 10 CFR 60.15(d), design flexibility as required in 10 CFR 60.133(b), and operational safety. This section is divided into five subsections. The first three subsections discuss various aspects of the interference concerns regarding construction and operation of the ESF, the experimental program, and the repository. The fourth subsection examines the flexibility of the ESF design and layout in handling variable geologic conditions, in incorporating additional

testing within the dedicated test area, in exploring other areas, and in reorienting or relocating certain experiments. The final section deals with operational safety concerns addressed in the design and their consistency with the governing regulations.

Three categories of potential interference concerns affecting the underground design and testing are discussed in the first three sections. In Section 8.4.2.3.6.1, the approach used to analyze the potential for test-to-test interference is described and applied to the current design layout. In the following section (8.4.2.3.6.2), test and construction/operations interferences are discussed, along with the means used to mitigate those concerns. The approach used to plan and coordinate the ESF layout and construction with that of the repository is discussed in Section 8.4.2.3.6.3. Within each of these sections, several mechanisms of potential interference were considered, principally those due to hydrologic, thermal, mechanical, and geochemical activity associated with the experiments (Table 8.4.2-14). Other potential sources of interference among tests or between the tests and the ESF construction and operations, such as ventilation, blast vibration, instrumentation, and traffic (including vibration), were also considered. The means used to limit interferences are discussed and analyzed relative to the current design. In general, potential interference problems can be limited through the use of physical separation (including orientation of tests), but other means are also used and their applications discussed. These include the sequencing of operations and testing to limit interference, control of operations such as blasting and fluid usage to limit the extent of changes induced in the rock mass, and monitoring and observation before accepting the location for testing. The application of these methods to the interference problem are discussed in the appropriate sections.

## 8.4.2.3.6.1 Potential for interference between tests

### Purpose and background

This section describes the general approach used to evaluate the potential for test-to-test interference among the experiments planned for the ESF and the use of this methodology in evaluating the current design layout of the ESF with respect to test-to-test interference. Each test proposed for the ESF is briefly described in Section 8.4.2.3.1. This section also discusses the constraints imposed on the underground layout by each experiment and the estimated zone of influence of each experiment. The design requirements generally arise from the requirement that the in situ conditions, such as stress state, degree of saturation, and temperature in the region where the experiment is to be conducted, not be altered by other activities in the ESF. Flexibility in choosing the final location and orientation of an experiment may also be an important constraint because of local variations in geology and fracture orientation. The zone of influence is intended to describe the extent to which each experiment alters or influences the surrounding region. In the conduct of each test, it is vital to ensure that the data derived from the test is not corrupted by the influence of other experiments that may be underway at the same time. The combination of experiment descriptions, design constraints, and zones of influence for each test, given in Sections 8.3.1 and 8.4.2.3.1, provides sufficient information to

evaluate the current ESF layout with regard to addressing concerns regarding test-to-test interference.

Approach

The approach taken to assess the potential for interference among the ESF experiments consisted of three basic steps. First, each experiment was evaluated with regard to potential interferences and zones of influence (Section 8.4.2.3.1). Several mechanisms for zones of influence and other potential interference sources were considered. For example, regions of material potentially affected or altered by an experiment due to heating, hydrologic alteration, geochemical reactions, and mechanical changes (excavation of drifts or thermally induced stress changes) were determined. Next, these four interference considerations and zones of influence for each test were combined and the one that gave the maximum zone of influence was translated into a physical area (standoff) requirement that represents the maximum extent of the rock zone affected by the test given the expected rock properties. These regions were then superimposed onto the design layout of the ESF test area. Finally, the overlay of zones of influence on the test locations was examined for potential interferences among the experiments.

The criteria for determining if a potential interference existed was to determine if the zone of influence of one experiment impinged on another experimental area to such a degree that the results of the experiment could be affected. To ensure conservatism in this approach, the potential for interference was considered high if the zones of influence of two experiments overlapped. Where the zones of interference for two or more experiments overlapped, the timing of the experiments and the type of interference (i.e., effect) resulting from the individual experiments were reviewed. If the tests were separated sufficiently in time to preclude an interference problem (i.e., one test may have been completed, with no unacceptable alteration of the rock, before the second was begun), the tests were considered to be independent of interference effects. If potential interference effects were found during the analysis, then adjustments to the timing or the layout of the experiments were considered.

The test-to-test interference concerns were completely evaluated using this methodology only for the experiments proposed for the main test level. Experiments and observational activities planned for the underground excavations were evaluated with regard to potential zones of influence (Section 8.4.2.3.1). Further evaluation was not, however, considered necessary because the tests involved primarily observational and sample collection, affected a limited amount of rock (see Section 8.4.2.3.1), or had large physical separations between them and other tests.

The principal mechanisms for creating zones of influence were considered to be thermal (for experiments using heat sources), mechanical (for experiments requiring extensive excavation), hydrologic (for experiments that introduced fluids to the environment) and geochemical (for experiments that altered the local in situ geochemistry). Other potential sources of interference, such as the location and extent of instrumentation (included in the mechanical category in Table 8.4.2-14), were also considered on a test-by-test basis. In general, most tests will have several zones of influence summarized in Table 8.4.2-14 resulting from different mechanisms. The effect

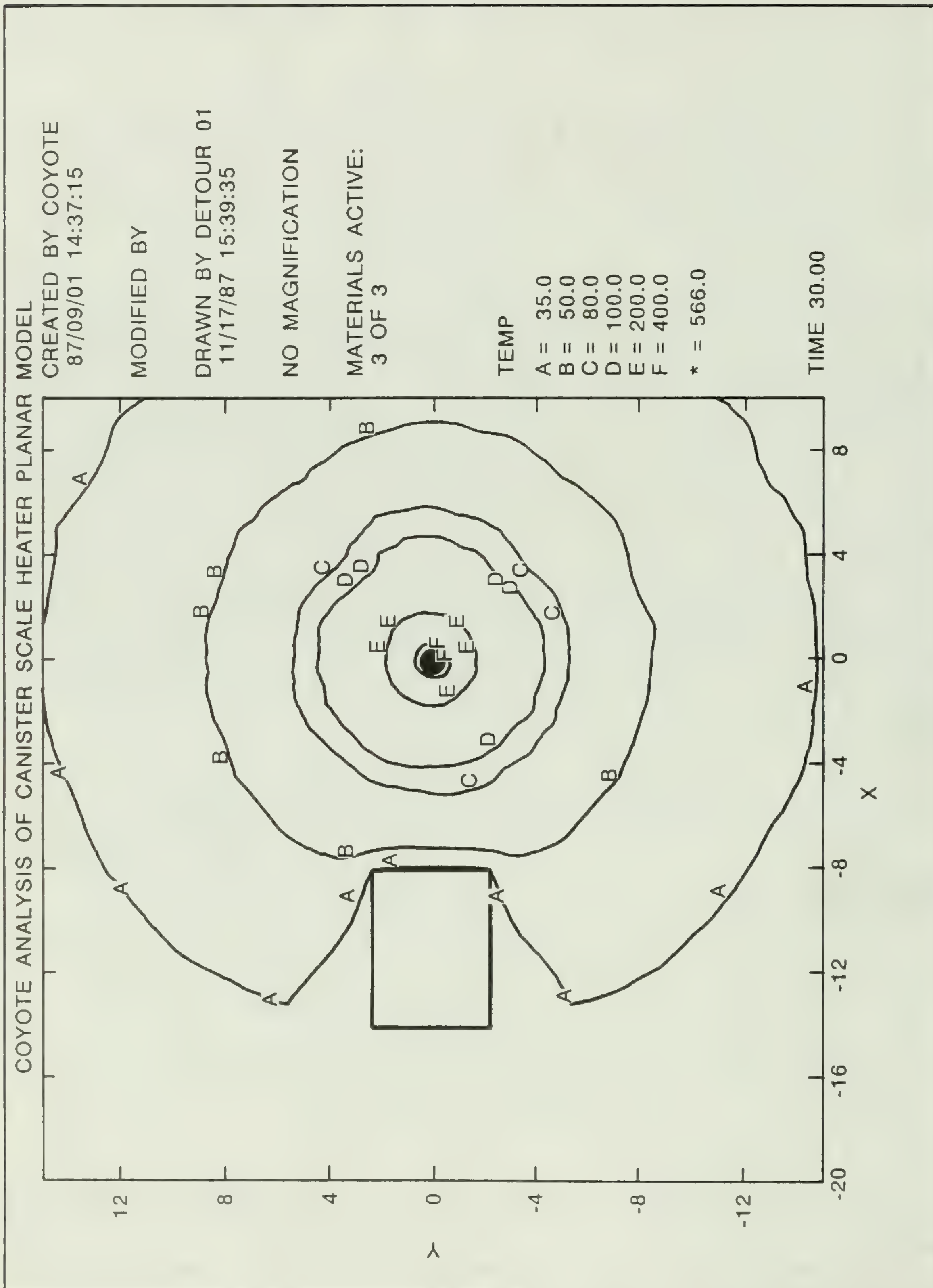
of some coupling of mechanisms was also considered. For example, heating the rock mass also affects the local hydrological and stress conditions. Analyses of these coupling effects are quite complex but generally depend on the gradient of the principal driving force. That is, hydrological and stress changes are a function of the thermal gradient. Therefore, the approach taken to account for these effects was to extend the zone of influence of the principal mechanism far enough so that gradients were low and secondary coupling effects would likely be contained within the zone defined by the principal mechanism. Thus, thermal zones of influence were extended to include all material surrounding an experiment whose temperature changed by more than 5°C.

The coupling of thermal and hydrologic zones of influence is also considered by Nitao (1988). In this investigation of thermal and hydrological behavior in the vicinity of the waste package, the region of condensed water vapor extends to approximately the same location (within 4 m) as the 80°C isotherm (approximately 50°C above ambient). As this water condenses, it is rapidly imbibed into the matrix (Martinez, 1988) where it remains relatively immobile (Eaton and Peterson, 1988). Since the 80°C isotherm is contained within the 5°C above ambient isotherm, the assignment of the 5°C isotherm as the boundary for the experimental zone of influence provides a conservative zone that addresses coupled thermal and hydrologic effects.

Geochemical and hydrological zones of influence were conservatively assumed to be identical where elevated temperatures are not encountered. At elevated temperatures (approximately 100°C), some geochemical alteration of tuff may occur (Smyth and Caporuscio, 1981; Smyth, 1982). However, beyond the boundary of the thermal zones of influence the temperature is assumed to be less than 5°C above ambient. This distinction between geochemical and hydrologic zones of influence need not be made.

Thermal zones of influence were estimated from preliminary thermal analyses performed in support of the experiment designs (for example, Bauer et al., 1988). The thermal zone of influence was taken to be the maximum extent of the isotherm that was 5°C above ambient temperature because temperature changes of less than 5°C are unlikely to have any measurable thermomechanical effect on the host rock. Thus, material outside the zone of influence was subjected to less than a 5°C temperature change. Figure 8.4.2-37 gives an example of such a thermal analysis for the canister-scale heater experiment. The view shown is looking along the axis of the heater with the instrument access drift shown 8 m to the left. After 30 months of operation, the 35°C isotherm (31°C is ambient) has extended approximately 12 m from the heater. The effect of the ventilated drift on heat conduction away from the heater is also evident. The effects of nearby drifts were factored into the estimation of thermal zones of influence where necessary.

Hydrologic zones of influence were estimated from pretest analyses, if available, or from generic studies such as those reviewed by West (1988) and are summarized in Section 8.4.3.2. The rock surrounding an experiment was considered to have been hydrologically altered if the in situ saturation change was more than 0.01. Changes in saturation of less than 0.01 are not considered appreciable and are difficult to measure with standard instrumentation.




PLANAR MODEL TEMPERATURE CONTOURS AT 30 MONTHS

**Figure 8.4.2-37.** Thermal analysis of canister scale heater test planar model.

Mechanical interferences from stress-altered regions around drifts and alcoves were estimated from preliminary structural analyses of the experiments (summarized in Section 8.4.3.2) such as those in Costin and Bauer (1988). Figure 8.4.2-38 gives an example of the expected alteration in stresses around the demonstration breakout drift (Costin and Bauer, 1988). In the figure, lines of constant vertical stress are shown as a percentage of the initial in situ stress. The figure shows that stresses differ by less than 10 percent from the in situ stress in the region beyond approximately one drift diameter from the wall of the drift. For tests where such analyses were not available, the results of generic analyses of repository size drifts were used. In general, structural analyses of underground openings using linear elastic (Hill, 1985; Johnson and Bauer, 1987; St. John, 1987 a,b,c) or nonlinear jointed rock mass models (Thomas, 1987) show that beyond one drift diameter (in a horizontal direction) from the wall of a long drift, the stresses are within 10 percent of the initial in situ stresses. Thus, a two-drift-diameter standoff around openings was maintained to account for the stress-altered zone around the opening.

Most of the structural analysis calculations performed to support the design of the ESF underground excavations and the thermomechanical testing used a linear elastic material model to simulate the rock mass. In many of these calculations, the elastic moduli are reduced from the measured values taken from intact rock samples in an attempt to account for the effect of joints and other discontinuities on the stiffness of the rock mass. But even when such efforts to account for the discontinuous nature of jointed rock are included in the analyses, the results from linear elastic calculations may not completely represent the behavior of the rock mass, especially in regions very close to the excavations. Very near the opening (usually within 1 to 3 meters), rock is loosened by the excavation process and stresses are reduced so that joints previously held intact by high normal forces may open or shear, resulting in displacements larger than predicted from elastic theory. The severity of this nonlinear rock response near mined openings depends on the nature of the rock mass. For example, Cording (1974) found that for openings where extensive rock loosening did not take place, the tunnel closure displacements predicted from elastic calculations were within a factor of two of the measured values. Where rock movement and loosening along joints was evident, measured displacements ranged from 3 to 10 times the predicted elastic displacements. Farther away from the opening, where stress gradients resulting from the excavation are low, the elastic analysis is generally accurate in predicting both the trend and magnitude of displacements.

Based on preliminary testing, the rock is expected to be relatively competent at the repository level. Although the rock is known to be fractured, elastic analyses will provide good estimates of rock behavior near excavations. However, before and during site characterization, several actions are being taken to ensure that the standoff requirements and drift stability estimates (based on elastic analyses) are conservative and to substantiate that the results of previous analyses of the underground excavations and experiments are reasonable. One ongoing effort is to look carefully at the existing mining experience in welded tuff. Prototype testing of excavation methods and instrumentation has been conducted in G-Tunnel on the Nevada Test Site. Zimmerman et al. (1988) reported the results of a mining experiment conducted in welded tuff. Careful measurements of rock motion and

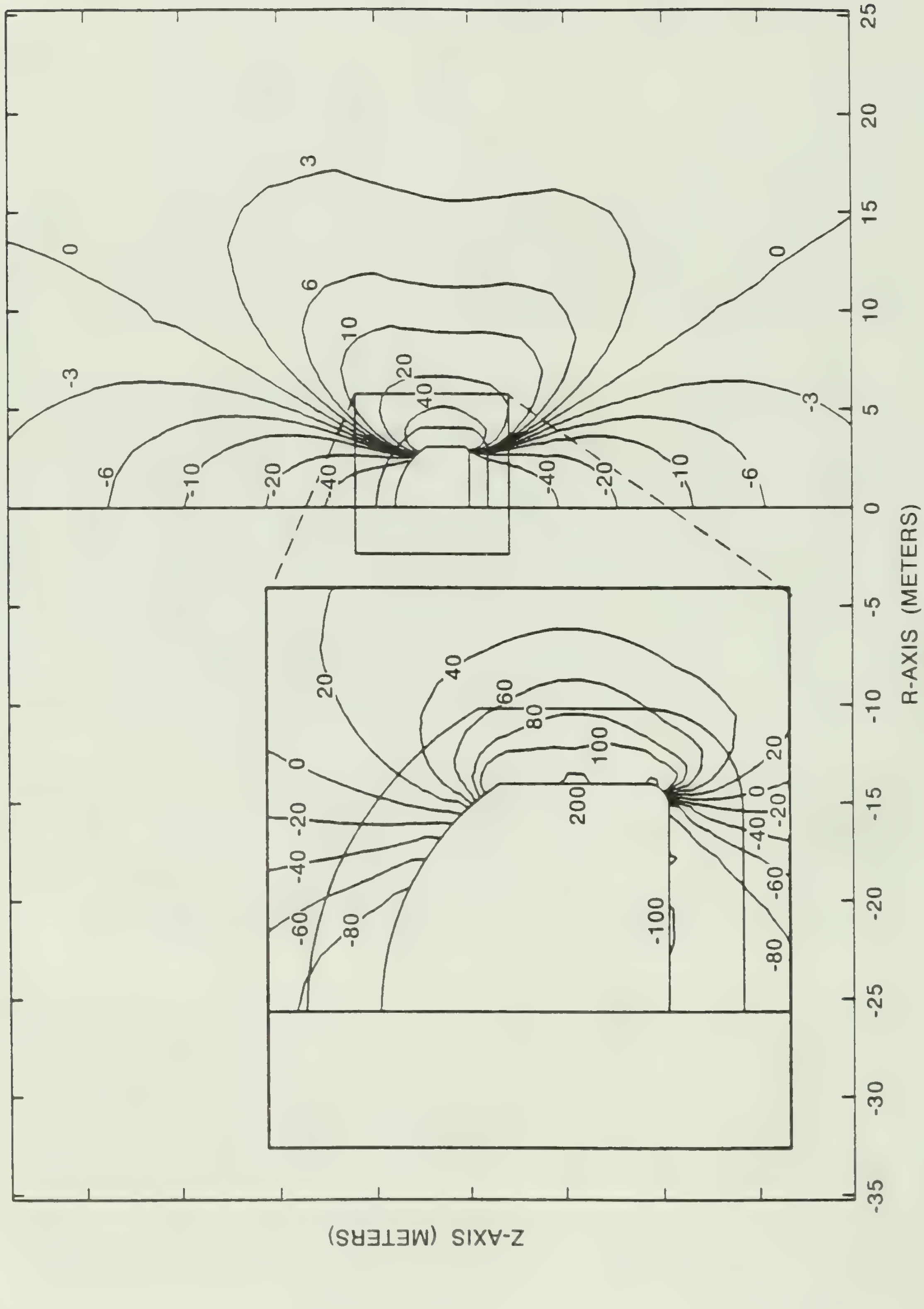



**Figure 8.4.2-38.** Analysis of demonstration breakout room—percentage change from in situ vertical stress.

permeability were made before mining the drift, during mining, and after an experimental drift (6.1 m wide by 4.0 m high, with an arched roof) was mined. Measurements of rock motion around the drift using MPBX gages that extended 15 m into the rock around the drift indicated that the measurable disturbance to the rock extended approximately 6 m laterally from the drift. As would be expected, the disturbance into the floor and ceiling were somewhat greater. Injection tests were also conducted to measure the hydraulic quotient of the rock in several boreholes. The hydraulic quotient is a measure of the apertures of fractures that are connected with the borehole in the region tested. From this testing, the fractures were found to be tighter after excavation than before, in most places near the excavation. Near a large fault through which the drift was mined, some rock loosening was noted. However, the measured hydraulic quotient only increased from the pre-mining value for 2 to 3 m into the drift wall. In addition, displacements predicted from an elastic analysis were generally found to be within a factor of 2 of the measured displacements, except near the fault, which was not taken into account in the calculations.

This preliminary evidence suggests that the results of the elastic analyses conducted so far should reasonably predict the structural response of the ESF underground excavations. An assumption of the acceptability of a two-drift-diameter standoff for precluding significant interference between test drifts and other mined areas seems conservative. Both analyses and preliminary measurements indicate that the stress-altered region around a drift will extend only approximately one drift diameter into the rocks.

With the exception of the diffusion test, geochemical alteration was not found to be sufficiently extensive as a primary mechanism to require a standoff region. The zone of influence due to diffusion of tracers in the diffusion test was estimated to be 0.3 m at the bottom of the borehole. This estimation was taken from previous field work using a similar technique (Birgersson and Neretnieks, 1982).

Other possible interference mechanisms were considered on a test-by-test basis. The extent of instrumentation for excavation deformation analyses was the most common reason for other mechanical zones of influence. Deformation gauges, such as multiple point borehole extensometers (MPBXs), extend 15 m into the rock surrounding an instrumented drift. For proper interpretation of the displacement measurements made from such gages, the bottom anchor should remain fixed, or move only as a result of displacements induced by the instrumented drift. If other drifts are constructed close to the bottom anchor during the period when measurements are being made, the bottom anchor may move and make interpretation of the displacement data more difficult. To preclude this, interference standoff zones for such instrumentation were included in the design so that no drifts would be constructed closer than two drift diameters from the bottom of the gages.

In defining the constraint and estimating the zones of influence for each test it was assumed that strict controls over water usage and blasting methods would be applied during construction of the test area. Therefore, the zone of hydrologically or chemically disturbed material created by these construction activities was not included in the zone of influence estimation for each test but rather is included in a general way in Section 8.4.2.3.6.2.

Hydrological or chemical zones of influence were determined only on the basis of the fluids and chemicals used in the test itself.

The zones of influence estimated for each experiment are based primarily on results of numerical analyses, results of prototype tests, and assumptions regarding the physical nature of the rock mass. One purpose of the early testing in ES-1 and on the main test level is to provide some data that may be used to confirm or adjust the estimated zone of influence resulting from the mechanisms described above. Specifically, the multipurpose boreholes and radial boreholes experiments will provide data on water transport near the shaft and allow for monitoring of a hydrologic zone of influence. Similarly, the demonstration breakout rooms and the heater test in TSw1 will provide thermal and mechanical data for comparison with current analyses. If estimated disturbed zones are found to be inadequate on the basis of early test results, needed adjustments and redesign can be completed before the experiments are set in place on the main test level.

Current assessment

An overlay of the zones of influence from the main test level experiments on the current (Title I design) dedicated test area layout is shown in Figure 8.4.2-39. Several of the 33 activities shown in Table 8.4.2-9 are not shown on the figure because those tests are to be conducted in ES-1 during construction, or involve only sampling or observations and, thus, have no specific location to be illustrated. The figure shows that the current layout provides sufficient separation between tests to preclude interference resulting from the mechanisms analyzed.

The drifts for demonstration breakout room (DBR) and the sequential drift mining tests are enclosed in fan-shaped regions representing the possible area affected by stress alteration resulting from construction of the drifts. The regions are fan-shaped because flexibility of orientation of the drifts was taken into account in developing the layout. The flexibility requirement results in having to set aside an area larger than would be required if the orientation of the drifts could be fixed at the present time. In addition to the orientation flexibility shown by the fan region, there is sufficient area available for the DBR and the sequential drift mining experiments that the layout could be completely rearranged within the area set aside for these tests (i.e., the experiment drifts could be reconfigured to be in a direction perpendicular to that shown in the layout). For other experiments, the flexibility requirement is satisfied by providing additional areas where the experiment could be conducted if the location shown in Figure 8.4.2-39 proves to be unsatisfactory. This is discussed further in Section 8.4.2.3.6.4.

For the DBR drift, Figure 8.4.2-39 shows both the early-time zone of mechanical influence and the additional standoff area that would be required if the displacement gages in the room are to be monitored for an extensive period of time. Note that developing the access drift to the northwest, which will connect to the long exploratory drifts in that area, may affect DBR instrumentation. The DBR experiment, however, is intended to provide early data on rock response that will be used in the development of later experiments. Therefore, measurements in the DBR should be completed before any further construction takes place, and no interference with construction

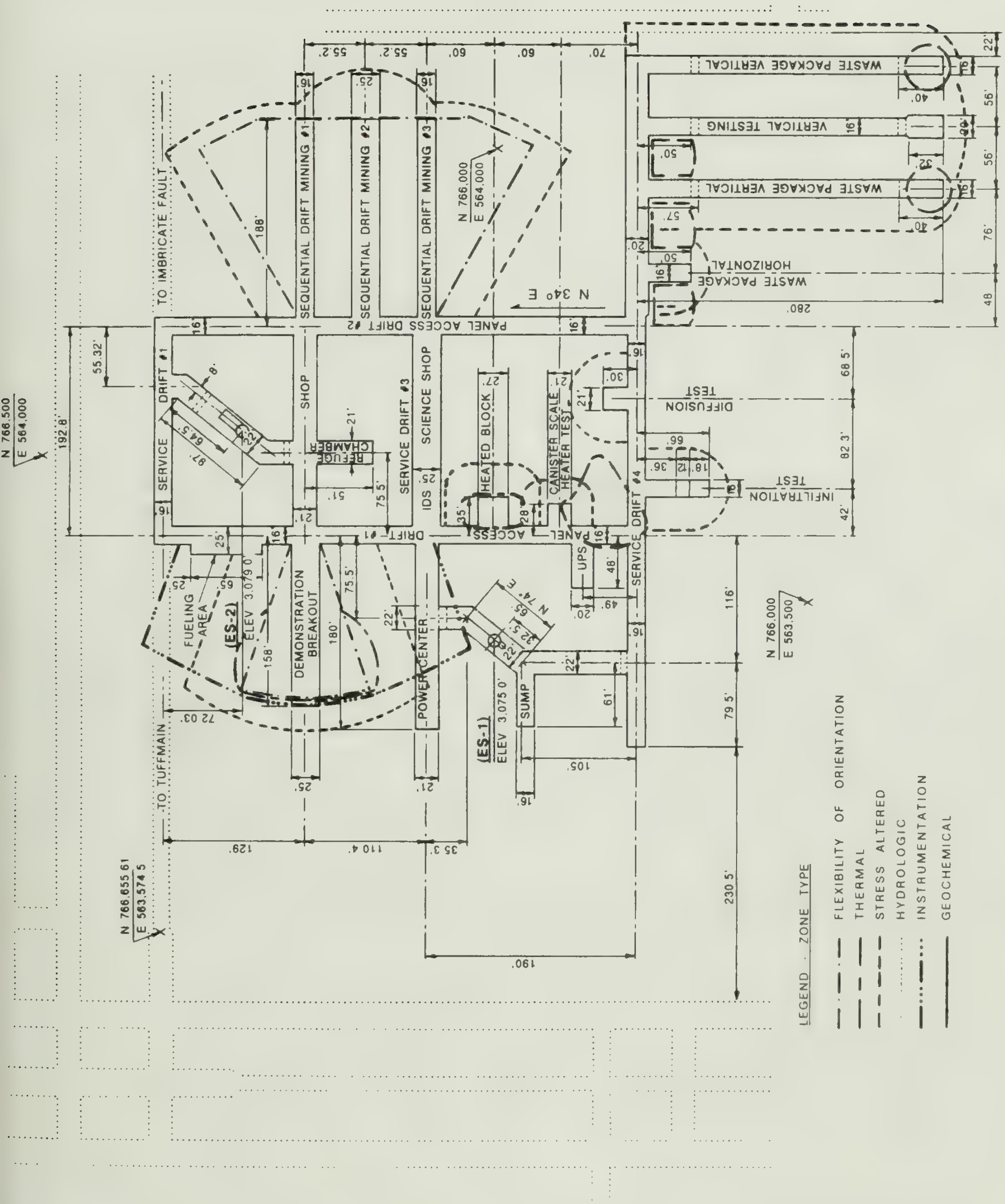



Figure 8.4.2-39. Zones of influence from main test level experiments on dedicated test area layout.

or other testing is expected. Additional area for instrumentation is not required for other excavation experiments such as the sequential drift mining experiment because the instrumentation is confined between the two outer access drifts. Also shown in the DBR is the thermal zone expected to result from the thermal stress test, if it is conducted in that area.

The principal thermal experiments shown on the layout include the canister-scale heater, the heated block, the thermal stress test, and the waste package environment tests. These tests are sufficiently separated that thermal effects will not pose a problem to other test areas. The canister-scale heater test provides the most severe thermal loading. The heater is located in the pillar formed by the intersection of two drifts, which not only provides instrumentation access from two directions, but also helps contain the region of elevated temperatures to near the intersection. The drift ventilation helps block the thermal load from conducting across the drifts. This produces the nonsymmetric shape of the thermal front shown in Figure 8.4.2-39. However, in the near field of the heater, where the principal thermal and mechanical measurements are to be made, the thermal field is axisymmetric about the canister (Bauer et al., 1988). The waste package tests are quite isolated in the southern end of the test area and have small zones of influence so test-to-test interference should not be a problem. Not shown on the current layout is the heated room test, which is intended to be located within the dedicated test area. Preliminary thermal and structural analyses have been completed for this experiment (Bauer et al., 1988), and zones of influence have been estimated for the proposed design. With this information, designers can locate the experiment (during Title II design) with due consideration for interference concerns.

The zone of influence for the infiltration test is small relative to the alcove where it is to be conducted. Thus, this test should not affect other nearby experiments or potential experiments that may be fielded in the dedicated test area. Similarly, the diffusion test affects only a narrow region near the borehole drilled from the diffusion test alcove. The central portion of the pillar containing the test should not be affected by the thermal experiments located in the northwest section of the pillar. Since the bulk permeability test areas have not been agreed upon yet, they are not shown. Because this test potentially could affect large areas with gas-phase pressure pulses, location relative to the longer-term, more sensitive tests located in the southern portion of the dedicated test area is of concern and will be addressed.

Like the heated room test the seal-component tests are not shown on the layout. Both tests are still in the early stages of design definition and will be added to the layout when the tests are approved.

This discussion indicates that the layout design is a dynamic and evolving process of refining and modifying the design. Thus, the information shown in Figure 8.4.2-39 represents a snapshot of the current state in this evolutionary process. New tests may be added and perhaps some of the currently defined tests may be changed, all of which will have some effect on the layout. These changes will be documented in the semiannual progress reports. Also, as the layout changes, the interference analysis (described earlier) will be updated as needed and used to ensure that changes will not produce unacceptable interference problems.

### 8.4.2.3.6.2 Potential for construction and operations interference with testing

Introduction and background

This section discusses the potential effect of construction and operation of the underground excavations on the conduct of the experimental program. In particular, the process used to evaluate the current layout and planned operations for potential interference with the testing program is described. Using this process, a current assessment of the construction and operations interference potential is then presented. Such assessments are an ongoing process and subject to frequent review as the design evolves and more data become available. The assessments are expected to be refined during the final preconstruction phase, during shaft construction when site-specific data become available, and during mining of the main test level when data for test locations and orientations become more specific. For the present, descriptions of the testing program, the ESF layout and the construction operations are given in Sections 8.4.2.3.1 through 8.4.2.3.5, which contain sufficient information to perform the evaluations described in this section.

Approach

The approach taken to evaluate the potential impact of construction and operations on the testing program consisted of both a forward and a backward evaluation method. The forward evaluation looked in detail at the description of planned operations. It specifically looked at the controls placed on those operations to reduce the effect of construction and operations on the testing environment and to determine whether those controls are sufficient to satisfy the constraints to the design imposed by the experiment plans (discussed in Section 8.4.2.3.1). Operational controls include such things as plans for blast control to limit damage to surrounding rock; control of fluids introduced in the shafts and main test level from mining or other sources; control of dust, vibration, and traffic near sensitive experimental areas; use of phased construction and testing; and inclusion of sufficient separation distances between experiments to reduce the potential for interference.

The backward evaluation consisted of looking at each constraint placed on the design by the experiment plans (Section 8.4.2.3.1) and determining whether ESF operations would satisfy that constraint. This part of the assessment included an evaluation of the sensitivity of each experiment to changes in the environment that may occur due to ESF operations. The experiments were evaluated with regard to their sensitivity to such operational considerations as ventilation changes; traffic; potential of excess water from surface flooding; and vibration, overpressure, and dust from nearby mining.

Current assessment

The earliest testing will be conducted during construction of the shafts. ES-1 will be used for scientific investigation, requiring that construction in that shaft cease while measurements are being made or instrumentation is being installed. ES-2 will be constructed in parallel with ES-1, using identical methods. One concern for the testing in ES-1 was the

simultaneous development of ES-2 and the effect it might have on hydrologic or structural measurements made in ES-1. The principal means for reducing the interference between the shafts are separation distance, construction methods, and control of fluids. Operational, safety, and testing interference concerns were all factors in evaluating the location of and the distance separating the shafts. Shafts need to be spaced close enough to allow reasonable distances for power instrument cabling and for water piping, and to provide for redundancy in mine water discharge. In addition, both shafts need to be located so that collars can be anchored in bedrock and be sufficiently above the drainage channel to preclude inundation by the probable maximum flood (PMF) (Section 8.4.3.2). It was also desirable to locate ES-2 close to a panel access drift but still provide for an adequate shaft pillar. This location provides for isolating operations such as dumping, haulage, and shops from the testing in the dedicated test area. The orientation of the hoisting operation is determined by the strike of Dead Yucca ridge. Thus, ES-2 is located as far away from ES-1 as practical to still have the desirable orientation and a suitable location relative to the ESF boundary. Safety considerations used to evaluate the ESF design are discussed in detail in Section 8.4.2.3.6.5.

For testing, the shafts must be sufficiently separated so that general hydrologic or structural interference between the shafts is unlikely. The 300 ft separation was analyzed for potential hydrologic interference by first identifying the fluid quantities likely to be used in ESF construction and then assessing the impacts of using those fluids. This impact of construction fluids was analyzed by West (1988) (Section 8.4.3.2.1.3, topic 2). Several calculations were performed to estimate the effects of construction water. First, the extent of matrix flow of water from the shaft was estimated (Section 8.4.3.2.1.3, topic 3) by estimating that 10 percent of the construction water (see Section 8.4.3.2.1.3, topic 2 for specific amounts) used in the shaft goes into the formation and is retained in a modified permeability zone, estimated to be one-shaft radius thick. In this instance, analysis shows that the water will slowly migrate outward from the opening so that, after 10 years, a zone 10 m in radius from the shaft centerline will have been affected by a change in saturation of approximately 0.08. The effect of hydrologic interaction due to water flow in fractures under pressure was also estimated (Section 8.4.3.2.1.2, topic 9). For small aperture fracture flow (24 to 100 μm opening), the results indicate that water moved 10 to 15 m vertically with a 20 m pressure head. For larger aperture fractures (250 μm), the water in the fracture may extend to 50 to 60 m from the shaft.

Because of the small amounts of water contained in the fractures, however, the water is predicted to be imbibed into the matrix, reaching an equilibrium state within a few days. The matrix adjacent to the fracture is predicted to return to nominal saturation state within a few weeks. These analysis and results indicate that, during construction, water would be expected to move short distances in the matrix or small aperture fractures and that changes in the rock mass saturation due to construction water are likely to be small. It was also noted that relatively large fractures are required to move water long distances. Occurrences of fluid transport were encountered in USW UZ-1 as a result of drilling of USW G-1 where it was evident that drilling fluid moved a great distance along possible geologic

structures in Drill Hole Wash. However, Drill Hole Wash may be along geologic structures, while the orientation of ES-1 and ES-2 is oblique to the apparent structural trends at Yucca Mountain. Further drilling operations planned for ESF construction will not result in the relatively high pressures that existed in drilling USW G-1 since there will be no large, standing columns of water. Therefore, substantially increasing (i.e., doubling or tripling) the shaft separation distance is not expected to significantly reduce the likelihood of some effect of one shaft on the other. In conclusion, then, the most likely source of water that could influence testing in ES-1 is the construction water used in ES-1.

Mechanical interference between the shafts was also considered. The zone of stress-altered rock surrounding the shaft was estimated from linear elastic calculations (summarized in Section 8.4.3.2) of a shaft with a 1.0-ft thick concrete liner subjected to horizontal and vertical in situ stresses (Costin and Bauer, 1988). The stress-altered region is assumed to be that region where the stresses vary by more than 10 percent from the in situ stresses. According to the calculations, this region extends approximately 5.5 m (1.5 shaft diameters) radially from the centerline of the shaft, and the region where the stresses vary by more than 1 percent from the in situ values extends approximately 16 m (4.5 shaft diameters). ES-1 and ES-2 are located approximately 20 shaft diameters apart. Therefore, mechanical interference between shafts is unlikely. Since both shafts will be constructed by drill and blast methods, blasting in ES-2 is not expected to affect experiments being conducted in ES-1 any more than blasting in ES-1 itself. Preliminary testing in G-Tunnel has demonstrated survivability of geomechanical instrumentation placed within 1.0 m of a full face blast (Zimmerman et al., 1988). Test results also indicate that the accuracy and calibration of the instrumentation are not affected by nearby blasting activities.
Figure 8.4.2-40 shows the estimated hydrologic and mechanical zones of influence of ES-1 and ES-2 projected on the plan view of the ESF main test level.

On the basis of these analyses, the location and separation distance of ES-1 and ES-2 are considered to be acceptable because (1) general hydrologic interference is not likely to be observed; (2) significant reductions in the probability of such an event are not likely to be gained by reasonable increases in shaft separation or by changes in the sequence of construction of ES-1 and ES-2, although the possibility of flow in large aperture fractures reaching the adjacent shaft cannot be precluded; (3) no mechanical interference or unacceptable vibratory interference is expected; and (4) the location and separation of the shafts is consistent with operational and industrial safety considerations.

The forward evaluation of the main test level layout considered whether the construction and operations considerations used in the design were compatible with the constraints placed on the layout by the experimental program (Table 8.4.2-13). A discussion of the principal operational considerations used in planning the layout and how they were satisfied follows.

First, the need to develop separate experiment areas and shop and training areas was included in the layout by placing the shop area close to ES-2 where most of the construction activities associated with development of the

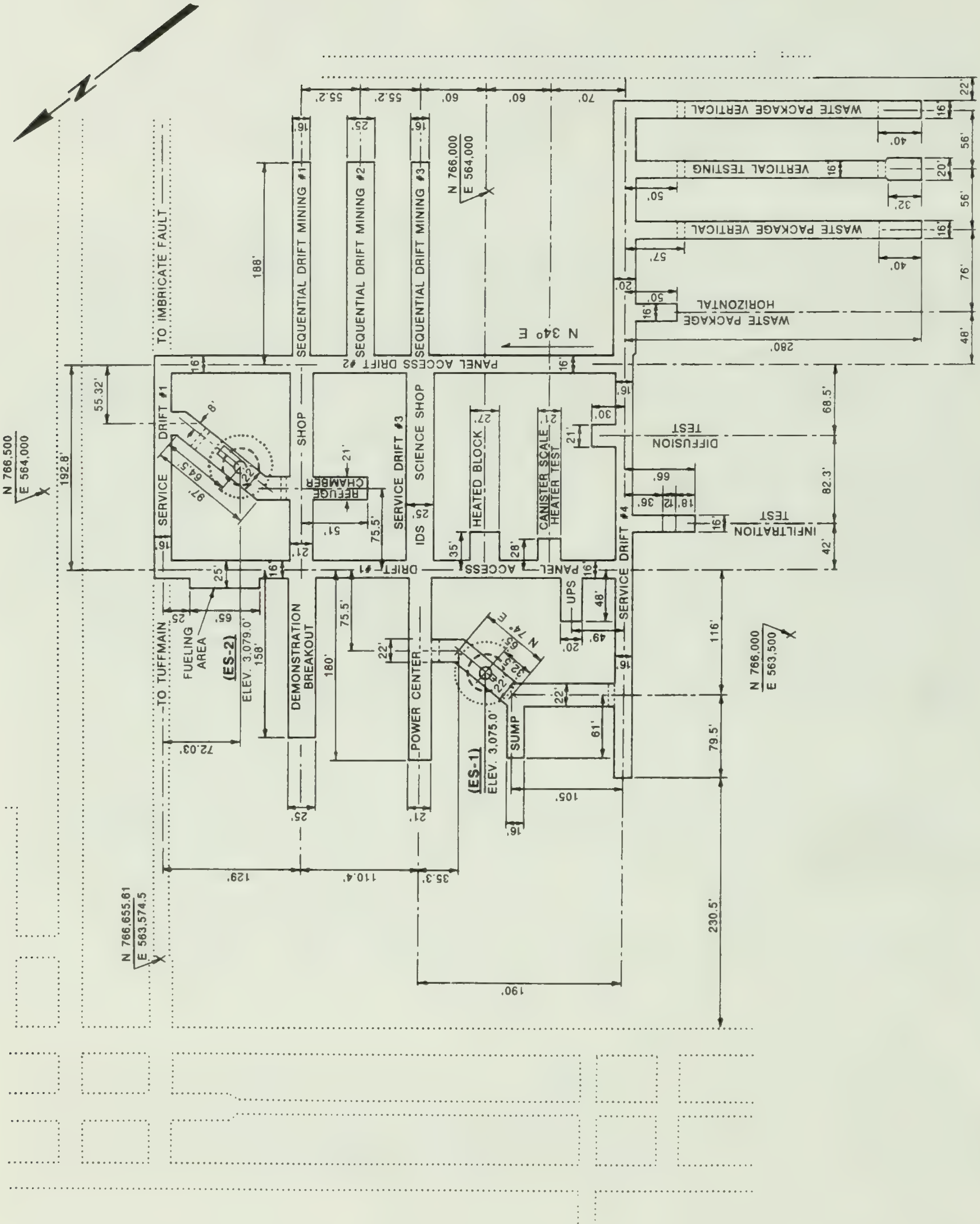



Figure 8.4.2-40. Hydrologic and mechanical zones of influence of exploratory shafts 1 and 2.

long lateral drifts are centered. This also allows such scheduling requirements as the need to develop service areas and facilities before experiment drifts are developed to be met. Safety considerations require that only limited mining be done before the two shafts are connected. The placement of the shop area drift also helps isolate more sensitive experiments located in the southern part of the dedicated test area from mine traffic. The nearby demonstration breakout room and sequential drift mining experiments are not affected by nearby construction or the additional traffic of mining equipment in the shop area.

Next, flexibility for experiments was included in the design by allowing additional area for experiments where orientation was critical and by including easy development into additional areas for future testing. Flexibility concerns are discussed in more detail in Section 8.4.2.3.6.4. The principal dedicated test area requirement was to adequately separate the tests from each other and from the potential repository area and to provide access for continued mining and construction activities while early tests were in progress. In addition, considerations, such as those for hoisting and ventilation, affect the room layout and main drift locations. Test-to-test separation considerations were used to determine spacing between experiments; more recently, detailed evaluations have been provided through analyses of zones of influence such as those discussed in Section 8.4.2.3.6.1. Other requirements, such as schedule and the degree of isolation from mining necessary to conduct each experiment are used in determining a specific area for the experiment. The orientation of the shaft stations was determined by hoisting and mucking requirements, but were consistent with the experimental program objective to limit mine traffic in the dedicated test area. The muck pocket for ES-2 is to the north side, allowing mine traffic to be limited to one service drift while developing the dedicated test area and allowing subsequent mining of the long exploratory drifts to proceed without having to disturb the dedicated test area.

The backward analysis of the layout was done to ensure that the experiment locations were consistent with the specific requirements of each experiment. Zones of influence and test-to-test interference were discussed in Section 8.4.2.3.6.1, demonstrating that the layout was consistent with those experimental considerations. Operational interference considerations included ensuring that (1) experiments to be done early in the ESF test plan were located close to the shafts or in drifts that would be mined early in the development; (2) experiments requiring isolation from the mining environment, such as the waste package experiment, were located farthest away from the shafts or in isolated drifts or alcoves; and (3) fluids in the underground area were adequately controlled to prevent contamination of sensitive experimental areas. Points 1 and 2 and the control of mining water in the shaft construction have already been discussed. The main test level layout was also evaluated for consistency with experimental requirements for fluid control. Infiltration of surface water due to an unusual influx of water down the shafts, such as from a flood at the surface, is considered unlikely to significantly impact testing activities because (1) the shaft collars are located above the PMF so that the probability of a large influx of water is very low; (2) the surface pad is designed to preclude water flow into the shafts; (3) diversion of water from the shaft into the test levels would be unlikely; and (4) the drifts are graded to drain toward the sumps located at

the shafts so that any unusual influx of water will flow away from experiments where control of fluids is important (such as the diffusion test, the waste package test, the infiltration test, the canister-scale heater test, and the heated block test.) In addition, the analysis presented for estimating the hydrologic disturbance from construction water used in the shafts was also used as a basis for estimating the hydrological zone of influence around mined drifts due to construction fluids. A 10-m hydrologic zone of influence around drifts was assumed. This estimate will be reevaluated when data from hydrologic experiments in ES-1, principally neutron probe measurements in radial boreholes test, become available. In most instances, the two-drift-diameter standoff region around the drifts was sufficient to preclude interference from mining fluids, as well as from the altered stress state. The sensitive hydrologic experiments are conducted from boreholes that penetrate beyond the estimated mechanical and hydrological zones.

The conclusions of analyses of the layout with regard to the potential for construction or operational interference are that the shaft locations, spacing, and underground layout are consistent with the constraints imposed on the design by the experimental program. In addition, no experimental constraints or requirements were found that were not addressed directly or indirectly by the design.

### 8.4.2.3.6.3 Integration of the exploratory shaft facility with the repository design

This section describes the general objectives and specific actions taken to plan and coordinate the ESF design and layout with the repository design in a manner consistent with the governing regulations (10 CFR 60.15(d)(3) and (4)). The specific intent of this effort is to ensure compatibility between the ESF and the repository designs and to limit potential interference between the ESF and the repository. The repository conceptual design is described in detail in Chapter 6 of the SCP and supported by detailed evaluations presented in the Site Characterization Plan Conceptual Design Report (SNL, 1987). The ESF testing, layout and operations are described in Sections 8.4.2.3.1 through 8.4.2.3.5. The more detailed design of the ESF developed during Title I design differs slightly from the ESF design in the repository conceptual design presented in Chapter 6. This is consistent with the repository design, however, because the repository configuration for the Chapter 6 evaluations does not require a detailed description of the ESF and was thus established much earlier than the completion of the ESF Title I design.

The general approach taken to limit ESF and repository interference focused on two compatibility concerns. First, the ESF was designed to maintain compatibility with the repository layout and operations. Particular attention was paid to ensuring that repository preclosure performance objectives (10 CFR 60.111), retrievability, and radiological health and safety were not compromised by any component of the ESF design. Second, steps were taken to ensure that the ESF design was compatible with postclosure considerations, particularly with the repository sealing objectives. Specific steps taken in the design to meet these two compatibility objectives are discussed below.

Compatibility with the preclosure performance objectives was addressed primarily by establishing the experiment drifts within the dedicated testing area at the repository level. Because it is a dedicated area, no waste is planned to be stored in the test area. A minimum of a two-drift-diameter standoff from repository drifts (resulting in an even greater standoff from waste emplacement areas) is also maintained to isolate the dedicated test area and reduce the probability that testing activities would interfere with or alter any part of the repository area. The dedicated test area was planned to support both site characterization and performance confirmation testing and to locate both close to support facilities. In addition, requirements were set to incorporate the test area within the repository block but near the boundary. This was so the test area would have a limited impact on the usable repository area and still retain the flexibility to expand without affecting the planned repository mains or panel access drifts (Section 8.4.2.3.3). Also, to limit the disturbance to the repository area, the long exploratory drifts were planned to be coincident with repository drifts (and at repository grade). These drifts will also be mined using methods and controls similar to those planned for the repository. Indeed, experience gained in mining these drifts will provide important input to the mining procedures used in the repository.

In the repository design presented in Chapter 6, configurations for both vertical and horizontal emplacement of waste were considered. The drift dimensions necessary to accommodate waste-handling equipment differ between the two emplacement configurations. The dimensions planned for some of the drifts to be constructed in the ESF will need to be modified after the Project selects the preferred emplacement configuration. These changes should enhance both consistency with repository design and direct application of data gathered in the testing program to the prediction of the response of repository openings.

Consistent with the design criteria in 10 CFR 60.134(b)(2) that require that seals not become pathways that compromise meeting the postclosure objectives, compatibility with repository sealing requirements was addressed in several ways. First, only a limited number of interconnections of the dedicated test area with the repository were allowed. These interconnections include long exploratory drifts, which will be used as repository drifts, and other drifts needed for ventilation. The standoff area between the dedicated test area and the repository area also provides a degree of isolation between the dedicated test area and the repository so that postclosure sealing questions are limited to the few interconnections. Additionally, any boreholes penetrating the repository horizon will be located in pillars to the extent practicable. Finally, a drainage plan was established that was compatible with repository operations and postclosure sealing concerns. Specifically, excess water entering the dedicated test area either through shaft flooding or encountering perched water zones will be expected to remain in the area and drain into the formation or to the ES-1 shaft sumps. The long exploratory drifts are graded to repository grades so that if repository construction proceeds they will be consistent with the repository drainage plan (drifts will slope away from the rooms in which waste is emplaced). The drainage features of the ESF layout and standoff between the testing and waste emplacement areas are consistent with meeting the additional design criteria of 10 CFR 60.133, particularly criteria (a)(1), (a)(2), (d), and (h).

8.4.2.3.6.4 Design flexibility

One of the design criteria in 10 CFR 60.133 is the requirement for flexibility of design (10 CFR 60.133(b)). That criterion requires the underground facility to have sufficient design flexibility to allow for necessary adjustments to accommodate specific site conditions. And since the ESF construction is exploratory, significant flexibility is necessary. A major aspect in the ESF design is to include sufficient flexibility (1) to provide alternative locations and orientations for the various experimental areas to ensure that geologic, hydrologic, and other constraint conditions or acceptance criteria on the location of the test can be met; (2) to incorporate additional tests within the dedicated test area; (3) to open additional areas to exploration and testing without significant impact on the repository; (4) to accommodate uncertainties or unusual site-specific conditions that may be encountered; and (5) to incorporate schedule changes allowing the more rapid development of some areas or the suspension of some activities while tests are performed. This section discusses the features of the design and layout of the ESF that address these flexibility concerns. The design and operations of the ESF are described in Sections 8.4.2.3.2 through 8.4.2.3.5, and test constraints and flexibility requirements are presented in Section 8.4.2.3.1.

Flexibility in the ESF layout is provided to allow for proper orientation of the major excavation experiments such as the demonstration breakout room and the sequential drift mining. Figure 8.4.2-39 shows the fan-shaped regions allowed for this flexibility assuming that the drifts will be driven starting from the location shown. Additional flexibility is provided for these excavations in that the drifts could be started from a different location along a service drift and still remain within the area allowed for the experiment. This flexibility is necessary because the exact location and orientation cannot be determined until development of the main test level has begun. Location flexibility is also provided for the other experiments, which have tentative locations shown on Figure 8.4.2-39. As shown, the experiments are widely spaced, not only to preclude interference problems discussed in Section 8.4.2.3.6.1, but also to allow for additional space in the dedicated test area that may be necessary to relocate tests if acceptance criteria for location of those tests cannot be met at the initial location. Tests listed in Table 8.4.2-12, but not explicitly located in the layout, have also been provided for in the design. Many of these tests are observational, require sample collection from many areas, or are to be conducted in ES-1.

Tests to be conducted in ES-1 have flexibility in location. Specific depths at which each test will be performed will not be determined until construction of the shaft reaches the depths where testing is planned. Because experiments, such as the perched-water test, will be conducted only if specific conditions (such as perched-water zones) are encountered in the shaft, flexibility in scheduling of activities is necessary.

The design also provides ample space for additional testing within the boundary of the dedicated test area. The space available within the dedicated test area for additional experiments with limited zones of influence is shown on Figure 8.4.2-39. If necessary, areas proposed for shops and training could be converted to provide additional space for the experimental

program. The shops and storage areas could then be relocated, possibly by developing the planned repository shops area that is nearby. Larger scale experiments can be incorporated by additional drifting within the dedicated test area. This is an option for incorporating the heated room experiment into the test plans.

Sufficient flexibility in the construction and operations plans to extend the scope of many of the planned activities and open additional regions for exploration or testing was included in the design. If deemed necessary, shaft sinking and mining operations could continue into the Calico Hills horizon or additional areas in the Topopah Spring Member could be explored by mining along planned repository drifts (at repository grade) as far as the planned repository boundary. Ventilation, hoisting, utilities, and other support facilities are designed to support additional mining capability (drilling jumbos, muck haulers, blasting crews, etc.) so that additional mining could be done without greatly compromising the schedule.

Uncertainties in ground conditions and water flow are always part of any mining operation. The underground design for the ESF, therefore, provides for flexibility in ground support to ensure stable drifts for all areas. The ground support design is based on rock quality determinations and, thus, is tailored to the specific ground conditions encountered. Additional ground support may be required in experimental areas where severe environmental conditions may be imposed on the rock mass. In addition, poor rock conditions or excessive water may be encountered in planned test areas requiring the relocation of some tests. As discussed previously, additional area is provided for this contingency.

The operational schedule for development of the underground areas and the coordination with testing activities has significant latitude to accommodate delays in the construction of ES-1 requested if additional testing is added. ES-1 and ES-2 are independent in that ES-2 could provide the utilities, ventilation, and other support to begin developing the underground while construction of ES-1 is completed. In addition, the design allows the rate of excavation to increase so that multiple test areas could be constructed simultaneously. Further mining capacity could be gained by adding mining equipment. The mining capacity is essentially limited only by the capacity of the ventilation system, which was designed with a capacity exceeding that required to support planned activities.

In conclusion, evaluations indicate that the current design layout has a great deal of inherent flexibility for arranging test activities. In addition, flexibility relative to changes in design, construction schedule, and experiment requirements have been considered. Finally, provisions or contingencies for handling changes that may be necessary during construction and experiment fielding have been considered.

## 8.4.2.3.6.5 Design and operational safety

### Introduction and background

This section discusses the impact of safety considerations on the design and operation of the surface facility and the underground excavations of the ESF. Safety concerns and regulations are a critical factor in the design process. All applicable codes and regulations regarding health and safety, as defined in DOE Order 5480.4, were followed in the design of the ESF. These include (1) the Mine Safety and Health Administration (MSHA) code 30 CFR 57, (2) the State of Nevada Revised Statutes (NRS) Title 46, (3) the California Administrative Code Tunnel Safety Order (CTSO) Title 8, (4) the California Administrative Code Mine Safety Order (CMSO) Title 8, and (5) the Occupational Safety and Health Administration code 29 CFR 1926. The surface facilities, the underground layout, and the ESF operations are reviewed in Sections 8.4.2.3.2 through 8.4.2.3.5. This section reviews those features of the ESF design most relevant to safety.

### Discussion

The design of the surface plan includes sufficient pad size and a general arrangement of features to ensure compliance with the applicable regulations. The design provides for a 100-ft standoff from all combustible materials (e.g., vegetation) for both shafts. The location and number of powder magazines to support the blasting is also determined primarily by regulation. Surface noise regulations are considered in the design of the ventilation fan systems. Finally, the road system was limited to 6 percent grades for heavy truck traffic and 10 percent grades for other traffic to limit safety hazards associated with the grades.

The underground excavation was designed so that adequate ground-support control could be maintained. This is accomplished by limiting the size and shapes of the drifts and the intersections to ensure that ground support can be designed to limit rock fall. The shaft pillar dimensions were established to ensure shaft stability. Both shafts are required to remain stable and operable to support underground activities. Two independent means of egress are required to be available at all times while personnel are underground, except during the limited period before the shafts are connected. For safe equipment operation, drifts and rooms are generally limited to less than 10 percent grade. Some exceptions to this limitation were made to incorporate test design requirements for adjacent drifts on different levels, for example, in the waste package environment experiments.

Consideration of safety concerns is evident in the design of the support and operations systems. Support systems include ground support, hoisting, ventilation, utilities (water, electrical, and compressed air), communications, and emergency escape systems. These are discussed in the following paragraphs.

The ground support system is based on a rock quality rating method and rock mechanics analyses. The requirements for support vary with the observed rock quality to ensure that all drifts will have the support necessary to maintain stability and limit the probability of rock fall in the area.

The hoisting system is designed with a capacity appropriate to the scale of the operation plus a substantial safety margin. The shafts include an overtravel region to provide a safety margin for the hoist system (shafts are mined to approximately 50 ft and 100 ft deeper than the main test level for ES-1 and ES-2, respectively). The shaft and hoist system also provide for an emergency escape capacity. Mine regulations require that two means of escape be available at all times except during initial development of the underground area. Thus, the initial mining must be primarily directed toward connecting the shafts. This is why the core area including the demonstration breakout room is to be mined first. Once the shafts are connected, more extensive underground operations are allowed within the regulations. With the two shafts and the emergency hoisting capability available, the design can satisfy the requirement that the underground facility can be evacuated within one hour by the normal means of egress (the shaft hoisting system). The ES-2 location was selected, in part, so that the muck handling activities taking place near the shaft station would be out of the main traffic area and isolated from general personnel access.

The ventilation system is designed with an overcapacity, primarily to allow for flexibility in the underground design (Section 8.4.2.3.6.4). This overcapacity, however, also includes a margin of safety for controlling dust and maintaining air quality in the ESF. The ventilation fans are reversible and ventilation control is provided so that in the event of a fire underground, the spread of the fire and the resulting smoke and fumes can be controlled with the ventilation system.

The utility substations for electrical distribution are isolated in separate alcoves to keep them out of the main traffic patterns and to limit exposure of personnel to high voltage equipment. The same concept is used for fuel stations for the mining and haulage equipment. In addition, an uninterruptable power supply is used, with backup generators to ensure that in the event of loss of power to the site, critical facilities and equipment will have backup power.

Besides the shaft and hoist systems for emergency egress, the underground design also includes a refuge chamber. This chamber is centrally located to the operations on the main test level so personnel will have a safe, controlled area to wait for evacuation if needed. As the long lateral drifts are extended away from the dedicated test area, additional refuge areas may be included for personnel working in areas remote from the shafts. The refuge chambers are equipped with emergency utilities and communications and are airlocked to provide a controlled atmosphere.

Operational aspects of the ESF related to safety include (1) the control of the traffic patterns to limit areas where personnel and heavy equipment must work at the same time, (2) the control and isolation of potentially hazardous areas such as the shops and equipment handling areas, and (3) the isolation of the shaft stations where dumping and mucking operations are concentrated.

As just discussed, the design process for both the surface and underground operations has considered safety as a paramount issue both through enforcement of codes and regulations in the design and through additional design constraints imposed to enhance safety of the project.

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*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

## *Volume VIII, Part B*

*Chapter 8, Section 8.4.3, Potential Impacts of Site Characterization on Postclosure Performance Objectives*

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*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

## 8.4.3 POTENTIAL IMPACTS OF SITE CHARACTERIZATION ACTIVITIES ON POSTCLOSURE PERFORMANCE OBJECTIVES

This section evaluates the potential impacts of the site characterization activities (as summarized in Section 8.4.2.2 and 8.4.2.3) on postclosure performance objectives and determines whether any of the activities might preclude the site from meeting those performance objectives. Both the Nuclear Waste Policy Act and 10 CFR Part 60 request an analysis of characterization activities that could affect the waste-isolation capabilities of the site. Because the unsaturated zone at Yucca Mountain is the primary repository system element the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site, considerable attention is given to the potential for impacts on the performance of this natural barrier.

Section 8.4.3.1 presents the postclosure objectives that will be addressed and discusses the approach to assessing potential performance impacts from site characterization activities. Section 8.4.3.2 presents information that is pertinent to evaluating the impacts of site characterization activities on site conditions and, subsequently, on the long-term performance of the site. The potential impacts of activities that could affect the postclosure performance objectives are evaluated in Section 8.4.3.3.

### 8.4.3.1 Introduction to postclosure performance objectives and approach to performance assessment

Subpart E of 10 CFR 60 describes the total system performance objective and three subsystem performance objectives for the postclosure period. The subsystem performance objectives are

> 10 CFR 60.113(a)(2): The geologic repository shall be located so that pre-waste-emplacement groundwater travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other time as may be approved or specified by the Commission.
>
> 10 CFR 60.113(a)(1)(ii): ...the engineered barrier system shall be designed, assuming anticipated processes and events, so that:
>
> (A) containment of HLW [high-level waste] within the waste packages will be substantially complete for a period to be determined by the Commission taking into account factors specified in 60.113(b) provided, that such period shall not be less than 300 years nor more than 1,000 years after permanent closure of the geologic repository;
>
> (B) the release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that

> this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

The total system performance objective is

> 10 CFR 60.112: The geologic setting shall be selected, and the engineered-barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to...standards...established by the Environmental Protection Agency.

The standards referred to in 10 CFR 60.112 are given in 40 CFR Part 191 and are now being revised by the Environmental Protection Agency. These standards require that the design of disposal systems provide a reasonable expectation that, for 10,000 years following permanent closure, cumulative releases of radionuclides to the accessible environment from all significant processes and events that may affect the geologic repository shall (1) have a likelihood of less than one chance in 10 of exceeding quantities calculated according to Table 1 of Appendix A to 40 CFR 191, and (2) have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated in accordance with that table.

Hereafter, for convenience, these four performance objectives will be referred to, respectively, as the ground-water travel time (GWTT) performance objective, the EBS release rate performance objective, the waste package containment performance objective, and the total system release performance objective.

In addition to addressing the four postclosure performance objectives, the evaluations in this section address or consider other regulations that are relevant to performing site characterization activities. For example, 10 CFR 60.15 lists requirements that address site characterization activities; and parts 60.133, 60.134, and 60.135 of title 10 list additional postclosure design criteria for the underground facility that may be relevant, with respect to construction, testing, and operation of the ESF, in evaluating potential impacts to postclosure performance objectives. In particular, Section 8.4.3.2.4 describes design features that address regulations listed in 10 CFR 60.133, 60.134, and 60.135 and that may contribute to the postclosure performance of the site. The evaluations in this section do not explicitly address the siting criteria of 10 CFR 60.122. Postclosure performance Issue 1.8, Section 8.3.5.17, addresses the NRC siting criteria. The strategy for resolving this issue ensures that the overall system performance assessment considers the site characteristics that are the basis for the NRC's siting criteria.

The regulations specify multiple performance objectives to stimulate a defense-in-depth, or multiple-barrier, philosophy. Using this approach, the performance of the repository system will be obtained from both natural and

engineered barriers. The GWTT performance objective is specified to ensure that the natural geologic formations of a site, with its current hydrologic conditions (i.e., before waste emplacement or construction), will have long ground-water travel times to the accessible environment and that the travel time along any likely potential radionuclide path will not be less than 1,000 years. The performance objectives for container lifetime and EBS release rate were formulated to ensure that the engineered components of the system (associated with the waste form) will contribute some performance to the overall system, providing an additional barrier to radionuclide release. The total-system-release performance objective is the overall performance objective; it designates the limit on the probability of release of radioactivity to the accessible environment over a 10,000-year period. The total-system-release performance objective must consider all significant processes and events that could occur over the 10,000-year period.

To identify and quantify the potential impacts of site characterization activities on postclosure performance of the site, the elements of the system that are important to evaluating the performance objectives must first be identified. The issue-resolution strategies of each postclosure performance issue define the components of the repository system that will be relied upon to contribute to performance in assessing the degree of compliance with the four performance objectives. The issue-resolution strategies for the four postclosure performance objectives are summarized in Sections 8.4.3.3.1 through 8.4.3.3.4 before potential impacts to the objectives are evaluated. For more discussion on the issue-resolution strategies for the performance objectives for total-system-release, container lifetime, EBS release rate, and GWTT, see Sections 8.3.5.13, 8.3.5.9, 8.3.5.10, and 8.3.5.12, respectively.

The unsaturated zone (as discussed in Section 8.4.1.3) at Yucca Mountain is the primary repository-system element that the DOE expects to rely on in demonstrating the waste-isolation capabilities of the site. Both the GWTT and the total-system performance objectives rely on the unsaturated Calico Hills nonwelded unit as the primary barrier. The container-lifetime objective based on the postemplacement environment of the waste package (the unsaturated Topopah Spring welded unit), as well as the waste container and the waste form. The EBS-release performance objective relies on both the engineered environment to control water contact with the waste and the waste form itself. In general, the primary manner by which site characterization activities could affect postclosure performance would be by altering the hydrologic or geochemical environment at Yucca Mountain. The evaluations made in Section 8.4.3.3 focus on changes to the hydrologic environment and how performance might be affected by those changes. Changes to the geochemical, geological, thermal, and mechanical environment are also considered as appropriate; the significance of most of these changes, however, lies primarily in their potential effects on the hydrologic environment.

### 8.4.3.1.1 General approach to performance assessment

Conceptual and mathematical models will be developed by the site characterization programs and will be the bases for the analytic techniques used to make performance assessments of the Yucca Mountain site. Preliminary

work has been performed to develop the alternative models of the site, the conditions currently considered in expected and unexpected scenarios, and the evaluations to date of how this system is predicted to behave with respect to the performance objectives in 10 CFR Part 60. This information has been documented in Chapters 1 through 7, and in Sections 8.3.1 through 8.3.5. Chapters 1 through 7 provide information on the natural and engineered components of the repository system. Section 8.3.1 discusses planned site characterization activities and the alternative hypotheses, or models, that the site activities will address. Sections 8.3.2 through 8.3.5 discuss the issues and proposed issue-resolution strategies to address the pertinent regulations.

An ongoing process of performance allocation has been initiated to identify the specific information considered necessary by preclosure and postclosure performance assessment to address the issues described in Sections 8.3.2 through 8.3.5. The site characterization program, described in Section 8.3.1, will provide the descriptions of the natural and engineered systems, physical processes, material properties, and boundary and initial conditions that are required to assess the performance of the Yucca Mountain repository system. Uncertainties in the provided information will be identified and quantified when possible. Performance assessments of the repository system will use the information to determine whether specific issues, related to regulatory requirements, can be resolved.

Because performance assessments will always be made to address specific issues, the models and information provided by the site characterization programs may be broader in scope than is required to resolve the issues. The process of performance assessment will often entail the simplification of models provided by the site characterization programs through the use of sensitivity analyses, bounding analyses, and uncertainty analyses. The simplified models will comprise the significant elements of the more general models to assess the performance of the repository system. For example, the hydrologic model for the unsaturated zone developed in the site characterization program will include descriptions of both liquid and vapor movement. If sensitivity and bounding analyses indicate that vapor movement does not significantly affect liquid water movement, it may be possible to use a simplified performance-assessment model that only includes phenomena of liquid water movement to evaluate the pre-waste-emplacement ground-water travel time performance objective. The more general site characterization models will be important for testing hypotheses, investigating coupled processes, and ensuring that no significant processes or conditions are being overlooked.

The performance-assessment models developed will be used to determine values for the performance and design measures identified within the specific issues in Sections 8.3.2 through 8.3.5. The analyses may be deterministic or probabilistic; probabilistic analyses will be needed to assess the uncertainties in the measures used to resolve the issues. Professional judgment, based on both site-specific and nonsite-specific information, will be used to evaluate the performance and design measures.

The models considered in assessing the performance of the site and developing issue-resolution strategies have been described in Chapters 1 through 7, in Section 8.3.1, and under the various issues addressing the

performance objectives. Because of the importance of the hydrologic conditions to assessing postclosure performance, the important hydrologic conditions and processes in the unsaturated zone at Yucca Mountain were described earlier in Section 8.4.1.3. A number of site characterization activities involve excavations in the unsaturated zone, and the considerations, discussed in Section 8.4.1.3, related to the possible effects of such excavations are summarized here.

1. Liquid-water flow occurs predominantly in the unsaturated rock matrix. Neither large-aperture fractures nor the excavations are expected to be conduits for water flow in the unsaturated zone under existing conditions. Fractures and excavations, however, must be examined as potential pathways for gas-phase, including water-vapor, movement.

2. Excavations will be backfilled with crushed tuff. The properties of this backfill will be such that, under expected conditions, it will also be unsaturated. This backfill will inhibit gas-phase flow and flow of surface water that might have access to these excavations. Water entering the backfill would be expected to be imbibed into the rock matrix.

3. If fluids are introduced into excavations during site characterization operations, these fluids are expected to be dispersed into the available rock matrix pore space within relatively short distances from the excavations. Furthermore, although localized flow in fractures could result from injected fluid, this flow would be ultimately imbibed and dispersed within the rock matrix.

4. Data from site characterization activities are required to determine the validity of the descriptions of conditions and processes at the site given in items one through three. The large uncertainties in the preliminary assessments of site performance cannot be quantified without data from site characterization activities.

These interpretations of current data are based primarily on physical concepts of unsaturated flow in a porous, fractured rock such as the rock at the repository horizon at the Yucca Mountain site. Continuous reevaluation of these interpretations will occur during site characterization as alternative models for unsaturated flow at Yucca Mountain are refined (Section 8.3.1.2.2). Furthermore, many aspects of alternative models of hydrologic behavior have already been considered in the evaluations of the potential impacts for both the nominal and disruptive scenario classes discussed in Section 8.4.3.3.1.2.

#### 8.4.3.1.2 Approach to assess the potential impacts of site characterization activities on the performance of the repository system

The approach taken to evaluate potential impacts of site characterization activities on performance is first to determine how each category of activity in both the surface-based testing and ESF testing programs could affect the thermal, mechanical, geochemical, and hydrological conditions at

the site. Second, the potential impacts on the postclosure performance objectives from these modified conditions are determined. Only those activities that will be performed within the repository conceptual perimeter-drift boundary will be considered. The effects on performance of the site from activities outside the site boundaries are expected to be much smaller than effects from similar activities occurring within the site boundaries.

The credibility of these and all other performance assessments of the repository system relies heavily on the degree of knowledge of the behavior of its important components. For the postclosure performance objectives, the major component, or barrier, important for assessing compliance with the regulations is the unsaturated zone. Little data is available that provides site-specific information on the hydrologic conditions and processes for the unsaturated zone at Yucca Mountain. Thus, a unique or completely defined model for the unsaturated zone cannot be constructed at this time. Eventually, the evaluation of potential impacts of site characterization activities on site performance will entail the application of well-developed fluid-flow and solute transport models. Specific models will differ with respect to the underlying conceptual model, the hydrologic-property data used, the boundary and initial conditions imposed, the system geometry assumed, and the hydrologic and other physical processes on which the models are based. The models will be designed to provide the most reliable estimates of site characterization impacts on specific performance measures that can be obtained from the quantity and quality of the available input data and parameters. Stochastic modeling techniques, coupled with the techniques of classical statistics or of geostatistics, can be used to estimate the uncertainties associated with the model calculations. In addition, sensitivity analyses will be performed for selected model parameters to estimate bounding or asymptotic limits. Such analyses are intended to provide conservative estimates of the uncertainty introduced by site characterization disturbances of the system in addition to the total uncertainty associated with the assessment of both postclosure and preclosure site performance. Without carrying out site characterization activities, the uncertainty in current estimates of the performance of the site generally cannot be quantified. For this reason, many of the analyses reported in Section 8.4.3.2 attempt to bound these uncertainties.

In addition to the conservative analyses used to assess possible effects of site-characterization activities, the DOE is taking a conservative approach to conducting site characterization itself. Because changes to the unsaturated hydrologic characteristics of site may potentially have the most significant impact of the long-term performance of the site, fluid and material usage will be strictly controlled. Fluid amounts will be limited to the extent practicable, and all water used will be tagged with a tracer so that possible changes to the site hydrologic conditions can be detected and monitored. The location of the exploratory shafts has been selected to preclude any significant impact on waste isolation, and construction methods will be used that will limit changes to the mechanical and hydrological properties of the site. These physical actions to be taken during site characterization are believed to limit, to the extent practicable, the potential deleterious impacts to the ability of the site to isolate waste.

Chapters 2, 3, and 4 contain the basic data describing the thermomechanical, hydrological, and geochemical conditions of the site. Section 8.4.3.2 draws on this information and on other analyses to describe how these conditions might be altered by the site characterization activities. This information is then used in Section 8.4.3.3 to evaluate the potential impacts of each category of site characterization activity on each postclosure performance objective. Potentially the most significant effects on site postclosure performance would occur because preferential pathways were created or the saturation distribution was altered by adding or removing water from the site. Therefore, the information presented in Section 8.4.3.2 focuses on the potential impacts on the unsaturated zone at Yucca Mountain to support evaluations in Section 8.4.3.3.

The site characterization activities are summarized in Section 8.4.2.2 (surface-based activities) and Section 8.4.2.3 (subsurface-based activities). In this section (8.4.3) the activities are grouped into five types:

1. Surface-related activities (e.g., pavements, trenches, ponding tests, road construction, dust control, drill-pad construction).

2. Drilling activities (e.g., boreholes).

3. Exploratory-shaft construction.

4. Underground construction of drifts and testing alcoves.

5. Testing activities in the exploratory shaft facility.

These categories of site characterization activities affect the chemical, hydrological, and thermomechanical conditions of the site in a similar manner because the penetrations and use of fluids and materials are similar. The significance of disturbances to the site conditions are evaluated, with respect to the four postclosure performance objectives. Disturbances are judged significant only when they are of such magnitude that they could potentially affect the capability of the site to meet the regulatory requirements of 10 CFR Part 60.

In Section 8.4.3.3, each of the four postclosure performance objectives is considered in evaluating the disturbances to the site conditions caused by the site characterization activities. The performance measures defined for the performance objectives are used in determining whether the disturbances are significant. A brief summary of the issue resolution strategy for addressing each performance objective is provided. The strategies identify the performance measures for the performance objectives. An extensive evaluation and discussion of the potential impacts of site characterization on the total system release performance objective is provided in Section 8.4.3.3.1, due to the implications of this performance objective for both natural and engineered barriers. The total-system-release performance objective must consider potential impacts from the site characterization activities on credible processes and events that could occur over the 10,000-yr period following closure. The processes and events discussed in the issue resolution strategy of the total-system-release objective (Section 8.3.5.13) are explicitly considered in evaluating the potential effects

of the categories of site characterization activities on that performance objective.

## 8.4.3.2 Supporting technical analyses and data

Analyses and data that evaluate potential impacts of site characterization activities on postclosure performance are summarized in this section. Although this section does not include all the information that will be used in the evaluations of Section 8.4.3.3, it does provide a representation of the quantitative site-specific information used to make the evaluations. These evaluations are based on preliminary hydrologic and physical-property data and on simplified conceptualizations of the hydrologic and physical processes operating within the unsaturated zone at the site. The information is divided into sections on hydrological information, geochemical information, and thermal/mechanical information. After these summaries, the information is used in Section 8.4.3.2.5 to estimate the perturbations to site conditions from the categories of site characterization activities described in Section 8.4.2. This discussion distinguishes between short-term, transient effects (e.g., controlled water use during drill-and-blast operations) and long-term, permanent changes (e.g., the creation of preferential pathways) that may affect the ability of the site to meet the postclosure performance objectives.

### 8.4.3.2.1 Hydrologic analyses and data

Hydrologic analyses and data that will be used in discussions of the potential impacts of site characterization activities on postclosure performance are summarized in this section. The hydrologic information is subdivided into sections on water infiltration from the surface (8.4.3.2.1.1), ground-water flow in matrix and fractures (8.4.3.2.1.2), redistribution of water retained in the unsaturated zone (8.4.3.2.1.3), and the movement of water vapor and air (8.4.3.2.1.4). In general, the information discussed will be used to infer how far water introduced from site characterization activities might penetrate into the rock formations, what the change in hydrologic conditions might be, how long these changes take to occur, and how long the change in hydrologic conditions might persist. Specific topics to be examined include changes in the magnitude and areal distribution of ground-water flux, changes in the distribution of hydrologic properties, and the creation of preferential pathways for radionuclide migration.

#### 8.4.3.2.1.1 Water infiltration from the surface

Site characterization and surface-preparation activities will cause some changes to the surface and possibly subsurface portions of Yucca Mountain. Site-specific analyses and data that are summarized indicate the potential effects on the site hydrological conditions caused by applying water to the surface of Yucca Mountain. From this information, the following discussion

develops preliminary inferences on how water from the surface is likely to infiltrate into the unsaturated zone at the site, on the time required for this water to reach the repository horizon, and on the possibility that surface water might reach the repository after entering an exploratory shaft. The inferences are numbered for ease in cross-referencing.

1. Low net infiltration. Net infiltration is that flux of water entering the unsaturated zone below the surficial plant-root zone and below that soil horizon from which direct evaporation of soil moisture into the atmosphere can occur. Net infiltration at the Yucca Mountain site is expected to be low because, under present conditions, the average annual precipitation is estimated not to exceed 150 mm (Quiring, 1983). The estimated potential evapotranspiration rate is on the order of 1,500 to 1,700 mm/yr (Kohler et al., 1959). Consequently, most of the precipitation received at the surface of Yucca Mountain probably is returned to the atmosphere.

Significant infiltration into the unsaturated zone, if any, probably occurs during infrequent floodwater runoff produced by isolated major storms. Surface runoff will tend to be concentrated into alluvial channels and basins or, possibly will be diverted into fault zones and fractures that could be favorable sites for infiltration. This hypothesis is being tested by detailed mapping of surficial materials at the site, artificial rainfall and surface-ponding experiments, and neutron moisture logging in a set of 74 boreholes distributed over the site (Section 8.3.1.2.1.2). The data from these activities will permit estimates of present-day net infiltration rates, the most probable maximum infiltration rates, and the probable areal distribution of net infiltration over the surface of the site.

Moisture contents measured to date by borehole neutron logging are consistent with the high potential for evapotranspiration, the relatively low annual precipitation, and the hypothesis of low net infiltration rates into the unsaturated zone under present conditions.

2. Effects of surface ponding. To evaluate situations that could result in deep percolation under present conditions, Peters and Gauthier (1988) simulated the potential effects of surface ponding on a fault zone at Yucca Mountain. The model for this analysis was a 1-D vertical column of hydrogeologic units defined by data from drillhole USW G-4. The model used the best available data for the hydrologic properties of these units. The initial pressure-head distribution within the column was based on a constant flux of 0.1 mm/yr through the column, with the water table at the bottom of the column. The fault was simulated as a highly transmissive zone in which the saturated hydraulic conductivity of the fracture system in each hydrogeologic unit was increased by a factor of 10,000. The pond was given an initial depth of 10 m, and the pressure head at the surface of the pond was set to zero. The saturated conductivity of the uppermost unit was high enough that 10 m of water infiltrated the surface in 2.2 days. This slug of water traveled through the Tiva Canyon welded (TCw) unit and most of the Paintbrush nonwelded (PTn) unit during this time. The flux at the surface was set at 0.1 mm/yr after 2.2 days. Because there was not enough water in the injected slug to saturate the entire PTn unit, the flow in the upper Topopah Spring welded (TSw1) unit, immediately below the PTn unit and above the repository horizon, was limited to matrix flow. The water in the PTn

unit slowly drained into the rock matrix of the lower units. The ground-water flux at the repository level did not change during the first 1,000 yr, but doubled during the time period between 10,000 and 100,000 yr, and returned to the initial conditions after about 200,000 yr. This calculation illustrates that a large short-duration perturbation at the surface, such as could be created by blockage of a wash, would be attenuated before reaching the repository horizon.

3. Water accumulation in the exploratory shaft. In another study of the entry of surface water, Fernandez et al. (1988) calculated an upper-bound estimate of the water flow into an unsealed, backfilled exploratory shaft from a major flooding event. This analysis evaluated the potential for water to accumulate in the shaft up to the level of the repository. At the currently proposed locations, the shafts will be collared in bedrock. The scenario analyzed by Fernandez et al. (1988) simulates ground-water flow in fractures that originates at the surface from flooding and intercepts the shafts and associated zones of modified permeability due to fracturing around the shafts at some depth below the surface. Because the shafts are located outside the channels for the probable maximum flood (PMF) storm, water is not expected to enter the exploratory shafts directly from the surface but could enter the shaft below the surface from water flow in fractures. To be conservative, the fracture network below the surface was assumed to easily communicate within the entire drainage basin, and water was not allowed to be imbibed into the unsaturated matrix tuff. These conditions allowed a greater volume of water to penetrate an exploratory shaft. Following a PMF, the analysis assumed that all the rainfall infiltrates into the ground either uniformly or only over a more restricted area defined by the existing water courses.

For these two cases, the total amount of water entering the two exploratory shafts was calculated to be 1250 $m^3$ and 1320 $m^3$ (330,000 gallons and 350,000 gallons), respectively. This calculation assumes no runoff and no imbibition of water from the fractures into the matrix. If these effects are included, the total water volume entering the exploratory shafts would more likely be one to two orders of magnitude less, or 10 to 100 $m^3$ (2,600 to 26,000 gallons) of water, respectively. Including the effects of shaft seals would, of course, reduce the volume of water even further. Fernandez et al. (1988) indicate that even the conservatively estimated volume of approximately 1,300 $m^3$ of water is well within the drainage capability of the sump at the bottom of the shaft. Fernandez et al. (1988) conclude that no water is expected to enter the repository through the shafts and contact waste material.

The above discussion leads to a question of the potential for accumulation of silt in the shaft sump. Accumulation of silt in the shaft sump is not expected to significantly reduce the drainage capability of the shaft for the following reasons:

a. It is within accepted engineering practice to engineer a backfill that is capable of preventing the migration of fine-grained material, such as silt (Khilar et al., 1985). This type of fines-migration barrier works on the principle of physical exclusion of fines whose median particle size exceeds one-third of the median pore or fracture size (Abrams, 1977; Herzig et al., 1970). For the

exploratory shaft sump, the average fracture aperture is not expected to be smaller than about 6 microns (Section 8.4.3.2.1.2) so that particles smaller than 2 microns will pass through these fractures without causing any plugging of the shaft sump. According to the work of Khilar et al. (1985), a material whose hydraulic conductivity is $10^{-4}$ cm/s will retain these fines and prevent siltation.

b. The exploratory shaft is located in a region where direct inflow of water is not expected. This is because the selected location is significantly above the level of flow that would result from a probable maximum flood and very large changes in the flow would have to occur for water to directly enter the shaft. Hence, it is expected that the interstices of the rock backfill will be dry and there is a small likelihood that a mechanism for significant fines migration will exist after initial emplacement of the backfill.

c. The response of the unsaturated zone to periodic flooding events is to remove water rapidly from fractures and backfill interstices into the rock matrix. The zone in which saturated flow exists is limited, and even for the extreme case studied by Peters (1988) (see Item b above), this zone does not propagate below the PTn unit. Hence, a significant mechanism for the movement of fines to the base of the sump is not likely to exist.

d. Near-surface water diversion from the exploratory shaft pad and an anchor-to-bedrock plug seal will further limit interstitial water movement within the exploratory shaft backfill.

e. The long distance transport of silt through the shaft seals to the base of the shaft is not expected since seals will likely block the movement of all but colloidal particles by the mechanisms mentioned in a. above.

In summary, under precipitation conditions similar to those occurring over the last four years, surficial water is not generally expected to move more than approximately 10 m downward through the porous alluvium and tuff with any measurable increase in saturation. The time required for a transient pulse of water to reach the depth of the repository horizon was estimated to exceed 1,000 yr. For flooding events, water from the surface might be expected to reach the repository horizon through a permeable feature (like a fault or unsealed shaft); however, the impact, if any, to hydrologic conditions at the horizon is expected to be localized and small. Information to support future evaluations will be obtained from Study 8.3.1.2.2.1.

### 8.4.3.2.1.2 Ground-water flow in matrix and fractures

As discussed in Section 8.4.1.3.1, for the current estimates of the ground-water flux through Yucca Mountain, the flow of water, if any, from land surface down to the water table will be primarily through the rock matrix. Many calculations have been performed for ground-water flow in the rock matrix; selected calculations that will be used in evaluating the

potential impacts of site characterization on performance are presented in the following summary, which also discusses laboratory measurements of water flow in the matrix of Yucca Mountain tuffs. Any rapid movement of water through large distances in the rock units of Yucca Mountain would probably require flow through fractures or structures like faults. Analyses have been performed using a composite model that includes the effects of fracture flow and matrix flow (see Peters and Klavetter 1988). This model does not explicitly simulate water flow in discrete fractures. To investigate the flow of water in fractures, analyses have been performed that model a fracture explicitly. Modeling studies can be used to infer how far water from site characterization activities might penetrate into the tuff matrix and fractures, how much the saturation might change, and how much time is required before the locally changed conditions return to near-equilibrium with the rest of the site. The following summaries provide information relevant to the role of the matrix and fractures in unsaturated-zone flow. The summaries are numbered for ease in cross-referencing.

1. Fracture aperture size. Few data are available to describe the internal geometry and aperture distribution within fractures. Peters et al. (1984) report measurements of hydraulic fracture apertures of 6 and 67 micrometers for two fractured cored samples from the Topopah Spring welded unit and hydraulic apertures values of 6, 22, and 31 micrometers for three samples from the Calico Hills nonwelded unit. Olsson (1988) reports physical apertures of 50-70 micrometers for unstressed fractures. Zimmerman and Finley (1987) summarize measurements of hydraulic apertures in the G-Tunnel facility on the Nevada Test Site, which range from 16 to 240 micrometers with the mean value being 90 micrometers. Evans and Nicholson (1986) report fracture aperture values in the range of 10 to 50 micrometers in densely welded tuff in southern Arizona.

2. Matrix hydraulic conductivity. Hydraulic conductivity values for saturated tuff matrix material are reported in Section 3.9 of this document. The values for densely welded tuff matrix, like those for the tuff of the repository horizon, have been measured to be approximately $10^{-11}$ m/s. The values of nonwelded tuff matrix, except for the nonwelded zeolitic Calico Hills tuff matrix, have been measured to be approximately $10^{-7}$ m/s. The matrix hydraulic conductivity of the nonwelded zeolitic Calico Hills tuff matrix has been measured at approximately $10^{-11}$ m/s.

3. Simulation of matrix response to increases in flux. Peters (1988) performed two sets of simulations of matrix flow. The simulations used a 1-D vertical column with the hydrologic stratigraphy based on data from drillhole USW G-4. The initial saturation levels were established by modeling a 0.1 mm/yr vertical ground-water flux through the column. The first simulation calculated the penetration of water into the rock matrix of the Topopah Spring welded unit at the repository horizon, here designated TSw2, when a boundary pressure head of 30 psi was applied for times between 1 and 100 minutes. These calculations were investigating the response of the matrix; therefore, fractures were not included in the model. The results indicated that the penetration was less than 5 cm into the matrix when using either saturated curves based on thermocouple psychrometer data (Klavetter and Peters, 1987) or saturation curves based on mercury-intrusion data (Rulon et al., 1986). The second set of calculations investigated the manner and rate at which changes in the percolation flux could propagate. The flux was

changed from 0.1 mm/yr to 0.5 mm/yr. Steady-state conditions in the top meter of the column were reached in hundreds of years using saturation curves for the matrix based on mercury-intrusion data, and in tens of thousands of years, using saturation curves for the matrix based on thermocouple psychrometer data.

4. Experimental data on matrix response to increased flux. Peterson et al. (1988) investigated the movement of water into tuff when a short (100 minute) 0.2-MPa water pulse was applied to a tuff sample. The movement of the water into the tuff sample, both during and after the water pulse was measured. As a result of the water pulse, changes in the initial saturation level after one hour were detected to a depth of approximately 1 cm. The saturation profile was measured for 21 days after the water pulse was terminated; at 21 days, measurable changes to the matrix saturation could be detected to a depth of approximately 2 cm.

5. Effects of changes in flux on travel time. Analyses of the change in water travel times resulting from changes in flux at the repository level were performed by Peters (1988), using a one-dimensional vertical column and a composite model of the fractures and matrix (Peters and Klavetter, 1988). Two water-flux histories were used in these analyses. One analysis used a water flux of 11 mm/yr for the first 90 years, 0.0 mm/yr between 90 and 1090 years, and 0.1 mm/yr until 1 million years. A second analysis used a water flux of 11 mm/yr for the first 90 years and 0.1 mm/yr until 1 million years. These calculations investigated the effect of water leaving the repository on water-particle travel times to the water table. Water particles were released throughout the column at a number of times, and the time required to reach the water table was calculated. The results indicated that there was a decrease in travel times for particles released during the first 90 yr into the zone near the repository. Their calculated travel times, however, exceeded 300,000 yr.

6. Effects of increased flux on saturation. A set of calculations was performed to investigate the possible effects of increased flux on flow characteristics in a layered, unsaturated system (Dudley et al., 1988). These calculations modeled a 1-D vertical column with the hydrogeologic units defined by data from drillhole USW G-4 using the composite fracture-matrix model (Peters and Klavetter, 1988). Both zeolitic and vitric properties for the Calico Hills unit were used. The steady-state saturation distribution was calculated for ground-water fluxes of 0.1, 0.5, and 4.0 mm/yr. For a flux of 0.1 mm/yr, the water percolated through the matrix over the entire length of the column. At a flux of 0.5 mm/yr, the water also percolated through the matrix over the entire length of the column. For a flux of 4.0 mm/yr, the water flowed through the fractures throughout most of the length of the column. Using the initial saturation levels calculated at fluxes of 0.1, 0.5, and 4.0 mm/yr, transient calculations were performed at twice the initial flux. These transient calculations indicated that the time required to change from the initial steady-state condition at a flux of 0.1 mm/yr to a steady-state condition of 0.2 mm/yr was hundreds of thousands of years. However, the change from a steady-state conditions at 4.0 mm/yr to a steady state at 8.0 mm/yr was calculated to require only a few years.

7. Rate of change of water table after major water-table rise. Two calculations were performed by Peters (1988) to simulate the drainage of

water after a major water-table rise using the composite fracture-matrix model (Peters and Klavetter, 1988). For one calculation, the water table was modeled to rise to the bottom of the TSw1 unit, and for the second calculation, the water table was modeled to rise to the land surface. For the flooded regions, the pressure head was set equal to -1 m. Except for the flooded region, the initial saturation was established by modeling a 0.1-mm/yr percolation flux through a 1-D vertical column with the hydrogeologic units defined by data from drillhole USW G-4. Following the water-table rise, the ground-water flux at the top of the unsaturated zone was set equal to 0.1 mm/yr. These calculations investigated the time necessary for water to drain from the flooded regions. After 10,000 years, the hydrologic conditions were still far from steady state in both calculations. At 10,000 years, the flux throughout most of the column was at least a factor of 10 more than the steady-state flux. For each calculation, about 200,000 yr was required to reach steady-state conditions.

8. Flux penetration into discrete fractures. Martinez (1988) analyzed capillary-driven water flow in a single discrete vertical fracture transecting a porous-media-representative of the hydrogeologic units at Yucca Mountain. Capillary-driven immiscible displacement of air by water along the fracture was induced by an abrupt change in water saturation at the fracture inlet. A 30-minute infiltration period was simulated for a 25-micrometer fracture, and moisture penetrations of 40 cm into a fracture in the Topopah Spring unit and 80 cm into the Tiva Canyon unit were calculated. Calculations for a 100-micrometer fracture with a 30-minute infiltration period indicated penetrations of 4.9 m and 9.8 m for Topopah Spring and Tiva Canyon units, respectively. Calculations are ongoing to investigate penetrations into fractures of different-sized apertures and using different inlet conditions.

9. Effects of drilling fluid on fracture-matrix saturation. The possible impact of drilling with water on the subsequent hydraulic behavior of a fracture-matrix system in a welded tuff was simulated numerically by Kwicklis and Hoxie (1988). The model simulated a block of Topopah Spring welded tuff (TSw2) that was bounded on one side by a vertical fracture whose hydraulic aperture was set equal to 24 micrometers. The initial matrix saturation was assumed to be 0.65, which corresponds to a pressure head of -11.0 m. The fracture was simulated as an equivalent porous medium whose hydrologic properties were analogous to those of a coarse sand. Initial equilibrium between the matrix and fracture was assumed. Analyses were performed with an imposed upper-boundary pressure head of either 0.2 m or 20 m for 1 hour at the surface of the TSw2 block. At the end of a 1-hour simulation time, the fracture was predicted to be saturated to a depth of about 0.5 m for the 0.2-m boundary pressure head. The depth of saturation within the fracture was calculated to increase to 2.1 m when a 20-m boundary pressure head was applied to the top of the block. If the fracture aperture was increased to 250 micrometers and the boundary pressure head was set equal to 0.2 m for 30 minutes, the calculated saturated depth within the fracture was 55 m. The relatively small amount of water contained in the fracture was quickly imbibed into the matrix. About 10 hours after the water was injected into a 24-micrometer fracture at a boundary pressure head of 20 m, the fracture saturation returned to within 0.05 saturation units of the initial value. The return to the initial saturation level for the matrix took longer, in that at 0.1 mm from the fracture-matrix interface, the saturation

was predicted to be 0.80 (the initial value was 0.65) after 24 hours. Several weeks were predicted to be required for the matrix to return to near-initial conditions.

10. Second analyses of effects of drilling fluid on fracture-matrix saturation. Bodvarsson et al. (1988) investigated the effects of drilling with gas and liquid water on fracture and matrix hydrologic conditions. The model used in these analyses simulated a block of Topopah Spring welded unit (TSw2) bounded on all sides by fractures. A fracture aperture of about 100 micrometers and a fracture spacing of 0.6 m were used. The initial saturation conditions were established by infiltrating a flux of 0.1 mm/yr through the model. An upper-boundary pressure head of 20 m of water head was placed on the system for 12.25 minutes to represent water drilling for most of the simulations. A water flux of 0.1 mm/yr was assumed after the boundary pressure head was removed. Water penetrated a vertical fracture to a depth of about 11.5 m. After simulated drilling stopped (12.25 minutes of the boundary pressure head), the fracture saturation returned to its initial value within in a few hours. In the matrix, the saturation returned to within 3 percent of the initial saturation within one month. These relatively short times to return to near initial conditions are because of the small change in the volume of water in the matrix and fractures in a local area. Similar results for the fracture penetration were calculated for a horizontal fracture.

11. Experimental results on matrix wetting. The isothermal imbibition of liquid water into initially dry (saturation <0.05), welded tuffaceous rock was measured by Reda (1986). The rock sample contained several microfractures transversely oriented to the direction of the wetting-front propagation. Water was forced into both ends of the sample at a pressure of 0.46 MPa, and water movement through the pore volume was monitored for 624 hours. The apparent maximum distance of detectable penetration of the liquid water after 29 hours was approximately 8 cm; after 97 hours, the distance penetrated was about 10 cm. The transverse microfractures slowed liquid water movement.

12. Field observations on drilling fluid migration. An apparent flow of drilling fluids from borehole USW G-1 to the vicinity of borehole USW UZ-1 has been observed (Whitfield, 1985). This possible occurrence of fluid movement between the two wells is indicated by the presence at USW UZ-1 of polymers that were used in the drilling of USW G-1 (Spengler et al., 1981). USW UZ-1 is located 305 m northwest of USW G-1 and was drilled approximately 3 years after USW G-1. Understanding how the water-polymer mixture moved so quickly at the site is important to understanding the processes and developing models for flow that are required to perform performance assessments of the site. Water, Waste & Land, Inc. (1986), in an unpublished report to the Nuclear Regulatory Commission, discusses some preliminary evaluations of the water flow between the two wells. Their analyses show that water flow through a single fracture under the influence of large pressure heads (2.7 MPa or 277 m of water head) can move over 300 m in 3 years. These results are similar to those presented in analyses just described. To prevent such fluid movement, future drilling operations, described in Section 8.4.2.1, will use dry-drilling techniques to the extent practical, will control water usage, and will not allow high heads of water to develop such as occurred in USW G-1.

The unpublished report, previously cited, also suggested that a perched-water zone may exist at the USW UZ-1 location or that the piezometric surface may be higher than indicated in Chapter 3 at well USW UZ-1 because of a discontinuity between the two wells. This hypotheses will be investigated by Activity 8.3.1.2.2.3.2. The evaluations also question the drainage capacity of the unsaturated Topopah Spring unit around USW UZ-1. If the piezometric surface is indeed higher than previously estimated, the bottom of the well may be within the saturated zone, and the data would not provide definitive information on the drainage of the unsaturated zone.

13. Fluid loss in borehole USW G-4. Compared with other fluid losses from existing holes, a relatively large amount of fluid was lost during the drilling of USW G-4. The borehole was drilled using an air-water-detergent mixture as drilling fluid and up to 343,000 gallons of this mixture were lost to the unsaturated zone during drilling operations. A full accounting of the fluid loss is problematical because of the presence of the detergent. The detergent would tend to reduce the surface tension of the fluid and, therefore, would inhibit imbibition of the fluid into the surrounding rock matrix. On the other hand, the detergent would enhance the physical adsorption of drilling fluid on exposed surfaces such as the borehole walls, and some of the fluid probably would be adsorbed into fractures that were intersected by the borehole. Because the drilling fluid was injected into the borehole under low head values, the depth of penetration of drilling fluid into fractures probably would be small. Following borehole completion, most of the adsorbed water would tend to drain back into the borehole as was indicated by a televiewer log that was run in the borehole two days after borehole completion. Consequently, it is reasonable to assume that most of the drilling fluid lost within the unsaturated zone would drain back into the borehole and flow downward to the water table, with only a small fraction of fluid actually being retained within the unsaturated zone.

The information summarized in this section suggests that water introduced under low pressures for relatively short times (as during the planned drill-and-blast operations) will move only a short distance (a few centimeters) into welded tuff matrix material. Because of the small volume of water that the matrix will accept, matrix saturation is likely to return to near-initial conditions within several weeks. For nonwelded tuff matrix with higher permeability, the distance of penetration would be somewhat higher and the time to return to near-initial saturation conditions shorter. The distance that water would be expected to travel in a fracture is highly dependent upon the fracture aperture, the water pressure head, and the period of time for which the fracture is exposed to the water. For average values of fracture apertures that are considered reasonable at the repository depth and below, and for relatively low pressures, the distance of water movement through the fracture is expected to be approximately 10 m or less. Because some fractures with large apertures will probably be present, the DOE expects that water will move several tens of meters in localized areas. The volume of water moving through an individual fracture will be relatively small and the estimated time for the water to be imbibed back into the tuff matrix is short (hours to days). The overall change to the rock saturation would be generally small. Data from USW UZ-1 (see number 12 above) suggest that a large volume of water can move a large distance through the extensive fracture networks at the site if extremely large water pressure heads are imposed. If air-water-foam drilling fluid mixtures are used, however, little

of the water introduced during drilling operations may be retained within the unsaturated zone. Nevertheless, water use during drilling and shaft construction will be strongly controlled (see Section 8.4.2) during site characterization activities.

The summaries also indicate that ground-water travel times are long and that the time required for transients to propagate through the system may be hundreds of thousands of years when the system is initially unsaturated. According to some analyses, increasing the steady-state ground-water flux by a factor of 2 may also mean that long times will be required for the system to reach the new steady-state condition. The Peters (1988) study (see number 5) predicts that short-term changes (90 years) in ground-water flux at the repository level will not significantly affect the long ground-water travel times that are predicted.

Section 8.3.1.2.2 describes several studies that will investigate water movement in the porous, fractured tuffs at Yucca Mountain through laboratory and in situ experiments and modeling. The effects of transients on the hydrologic system will also be investigated.

### 8.4.3.2.1.3 Redistribution of water retained in the unsaturated zone

This section compares the quantity of water expected to be used during site characterization with the quantity of water present at the site in the interstitial pore space and with the quantity of water that is received annually on the site from precipitation. The following paragraphs summarize predictions of the extent of the potential changes in the average saturation of the rock mass in the disturbed portion immediately around an exploratory shaft. The predictions are numbered for ease in cross-referencing.

1. Water introduced through surface activities. The amount of water that will be used during site characterization activities is small compared with the amount of precipitation that is received annually on the site. Surface-based site characterization activities are expected to disturb approximately 10 percent of the surface area within the conceptual perimeter-drift boundary (CPDB) (Section 8.4.2.2). The Project has applied for a maximum water use of 131 million gallons over 6 years. Actual water use is expected to be somewhat lower (approximately 73.8 million gallons; Section 8.4.2.2.2). Therefore, a maximum of 131 million gallons of water could be introduced to the site during site characterization (assuming approximately 5 years of site characterization work), with approximately 68 percent (or 86.6 million gallons) of that total being used for dust control. The majority of the water used for surface activities is expected to be lost from the surface through evaporation. The impacts of water added to the surface by ESF pad construction activities on existing hydrologic conditions will be examined. If a need exists to determine the pre- and post-pad construction hydrologic conditions at the site of construction activities, then activities necessary to obtain information will be developed. Comparatively, an average of about 230 million gallons of water per year falls on the surface of the proposed site from normal precipitation (based on an annual precipitation rate of 150 mm/yr and an area of approximately 1,400 acres within the conceptual perimeter drift boundary (CPDB). Thus, an

average value of approximately 23 million gallons of precipitation would be expected to fall on area within the CPDB disturbed by site characterization activities (about 10 percent of the area of the CPDB). For the surface area expected to be disturbed over a 5-year period of site characterization, over 100 million gallons of water will be applied. According to the pan evaporation rate of 1500 to 1700 mm/yr (Kohler et al., 1959), the volume of water within the CPDB introduced to the surface that could be accounted for by evaporation would be approximately 2 billion gallons per year. Because of the differences between evaporation from a free-water body and evaporation from soils, actual evaporation is expected to be less than this amount. However, the volume of water actually evaporated is expected to be a considerably larger volume than will be introduced to the surface of the site by either precipitation or site characterization.

2. Effect of water used during exploratory shaft construction. West (1988) has estimated that approximately 10 percent of the water introduced in the subsurface during shaft construction will not be recovered and is assumed to be retained within the unsaturated zone. To investigate the potential effects of the retained water on the in situ conditions, the potential distance this water could move and the effects on the initial saturation levels were analyzed. Eaton and Peterson (1988) calculated the potential changes in saturation that could result from the construction water retained during exploratory shaft construction. West (1988) estimated that 3.02 $m^3$ of water per meter of shaft depth and 1.65 $m^3$ of water per meter of drift length would be used during construction. Ten percent of the construction water was estimated to be retained in the rock. Calculations were performed for both shaft and drift geometries to determine the distance the retained construction water could move from the surface into the rock, assuming the water initially saturated the fractures and was not adsorbed into the matrix. The analyses assumed a uniform distribution of the retained water around the shaft and drifts. The distance the water would penetrate from the shaft wall depended on the effective porosity of the fracture. The farther the water flowed in the fracture (as a result of decreasing fracture porosity), the smaller the change in the initial saturation level. The change in initial matrix saturation was 0.0017 at the proposed repository horizon. This occurred after equilibrium was established between the matrix and water-filled fractures. Doubling the water volume retained per unit length of shaft or drift would double the change in saturation.

3. Effects of water on the modified permeability zone. Eaton and Peterson (1988) analyzed the radial flow of water that may be retained around the exploratory shaft during construction. For these analyses, West (1988) estimated that 10 percent of the construction water was retained in the matrix around the shaft in the modified permeability zone (MPZ). The MPZ is the disturbed zone around the shaft and is expected to extend approximately 2.2 m into the rock mass (Case and Kelsall, 1987). The hydrogeologic units were defined by data from drillhole USW G-4, and the initial saturation values were assumed to be those corresponding to a constant 0.1-mm/yr vertically downward ground-water flux. The time-dependent, one-dimensional radial flow of the retained construction water into the rock matrix adjacent to a shaft liner was calculated by Eaton and Peterson (1988). The water was assumed to be in isothermal matrix/fracture equilibrium at all times. At the end of one year, the maximum change in saturation in the MPZ for the Topopah Spring welded tuff matrix was about 0.035 above the nominal value of 0.65.

After two years, the saturation in the MPZ was 0.03 higher than nominal, with small changes in saturation (<0.005) calculated at 10 m from the shaft centerline. In all instances, the saturation increase at radial distances greater than 5 m from the shaft centerline (0.6 m from the MPZ) was less than 0.03. The largest initial increase in saturation in the MPZ from the retained construction water was 0.08 for the Tiva Canyon unit.

In summary, the volume of water to be introduced to the site during site characterization is comparable to the volume of water from annual precipitation. Global redistribution of water that will be retained in the rock from mining the shafts is not expected to significantly change the initial matrix saturation profile, either near the surface or at depth. The farther the water moves from the shaft wall, the smaller the change in the matrix saturation profile. Figure 8.4.3-1 shows the estimated change in matrix saturation as a function of distance from an exploratory shaft if the water estimated to be lost from construction is distributed uniformly around the shaft. If the construction water is initially retained in the MPZ, the radial movement into the matrix is estimated to be very slow and to produce very small changes in the initial ambient saturation distribution. As will be described in the next section, the amount of water retained in the unsaturated zone may also be significantly affected by ventilation of the underground repository or exploratory shaft openings.

### 8.4.3.2.1.4 Movement of water vapor and air

In addition to the possible removal of water vapor from the proposed repository environment by natural processes, water-vapor removal may be induced by human disturbances, such as boreholes and shafts. Chapter 3 indicates that barometric and topographic effects at Yucca Mountain may result in air and water-vapor exchange between the fractured tuffs in the unsaturated zone and the atmosphere. Water-vapor flow from the unsaturated-zone has been observed to occur from an open borehole penetrating a fractured tuff horizon within the unsaturated zone (Weeks, 1987). Analyses have been performed to investigate the effects of this exchange, and are summarized in the following discussion. The ventilation system to be installed in the exploratory shaft facility will remove water vapor from the unsaturated zone. To investigate the potential effects of the ventilation system on the saturation level in the rock matrix, two calculations were performed. These analyses are also summarized in the following discussion. The analyses are numbered for ease of cross-referencing.

1. Water-vapor flow in an open borehole. Substantial air exchange between the atmosphere and two wells (USW UZ-6 and USW UZ-6s), located at the crest of Yucca Mountain and penetrating highly fractured welded tuffs, was observed by Weeks (1987). Well USW UZ-6 was drilled to a depth of 575 m; well USW UZ-6s was drilled to a depth of 158 m. During the winter, the wells exhausted air almost continuously at a velocity of about 3 m/s. During the summer, the wells alternately take in and exhaust air at much lower velocities than occur during the winter, and the flow directions typically reverse a few times a day. The cause of the air flow is presumably a consequence of both topographic and barometric effects. While topographic and barometric effects appear adequate to explain the air flow during summer, the magnitude

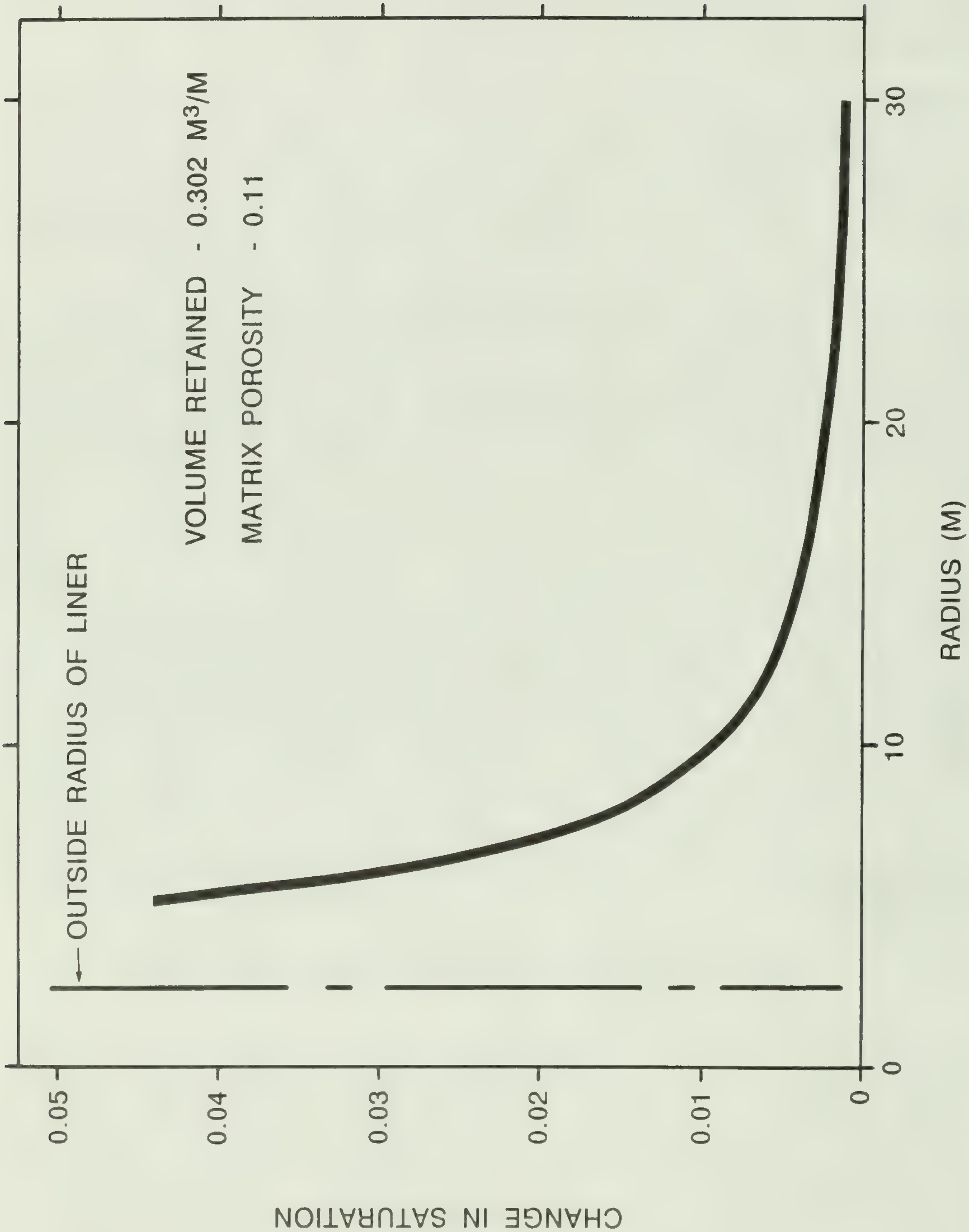


**Figure 8.4.3-1.** Effect of radius of area containing retained construction water or change in saturation.

of the air flow in the winter seems to exceed the flow that could be caused by these mechanisms. Naturally occurring air flow out of the unsaturated zone of the site would tend to dry the rock in the upper part of the unsaturated zone (for example, the upper 125 m of rock composed of the fractured Tiva Canyon welded unit) and could produce low liquid-water fluxes at the proposed repository horizon. No data are available, however, to indicate that air movement into or out of the unsaturated zone occurs at repository depths under natural conditions.

2. Air and water vapor flow. Kipp (1987) performed numerical analyses to investigate the effect of seasonal variations in air temperature at the surface of Yucca Mountain, coupled with topographic relief, on potential air and vapor flow in the unsaturated zone. Analyses cover the upper 150 m of the simulated mountain, and it was assumed that integrated, connected pneumatic pathways (for example, open fracture systems) existed through which air movement could occur. The calculated air-velocity fields and boundary fluxes indicated that minor atmospheric circulation can be induced through the mountain. For boundary conditions representative of summer conditions, air enters along the crest and leaves along the side of the mountain. For boundary conditions representative of winter conditions, the air flow is out at the crest and in along the side of the mountain. This analysis did not include the effect of a borehole. The calculated net water-vapor transport out of the mountain was very small, but as noted by Kipp (1987), this result may have been due to model simplification and parameter uncertainty.

3. Air flow through backfill. An analysis of the convective air flow through the rock, shafts, and ramps was performed by Fernandez et al. (1988). Air flow was calculated by assembling a "network stiffness matrix" of various resistances representing the network of underground openings and the rock mass. A pressure and temperature boundary condition was applied to this network, and the total air flow was calculated; heat effects from emplaced waste were not considered. The analysis indicated that the percentage of air flow through the exploratory shafts depended on the air conductivity of the backfill. The study concluded that the exploratory shafts will not become preferential pathways for gas flow if the air conductivity of the backfill is less than about $3 \times 10^{-4}$ m/min. This conductivity value can be expected to be achieved using crushed tuff as the backfill or stemming material.

4. Barometric effects on air flow in the shaft. Fernandez et al. (1988) also evaluated the potential volume of air removed from the backfilled exploratory shafts due to barometric changes at the surface. Three weather events were modeled: a severe thunderstorm, a tornado, and seasonal barometric pressure fluctuations for one year. Comparing the calculated air volume displaced from the exploratory shaft for the weather events considered, the severe thunderstorm displaced the largest volume, followed by the seasonal barometric fluctuation and the tornado. These analyses indicated that for the weather events modeled, and a backfill with air conductivity of $\leq 3 \times 10^{-4}$ m/min, the backfill would effectively isolate the repository air from barometric-pressure fluctuations and restrict the displaced air to a small proportion of the total shaft air volume.

5. Air-drilling effects on saturation. Bodvarsson et al. (1988) investigated the effects of air-drilling on the surrounding rock, assuming an upper-boundary air pressure head of 2 bars. As in the water-drilling

analyses by West (1988) discussed earlier, the air drilling was assumed to occur for 12.25 min. Only small changes (<0.005) in saturation were calculated in the rock matrix less than 1 cm from the disturbed surface. Air-pressure changes were calculated to a depth of 3 m in the interior of the matrix, while the air-pressure pulse in the fracture extended over the entire block modeled. The recovery of the air pressure was rapid with near-initial conditions reached after about one day.

6. Experimental drying of tuffaceous rock. Russo and Reda (1988) investigated the drying of an initially saturated tuff. For this investigation an initially saturated, welded tuffaceous rock was isothermally dried, and the saturation distribution monitored for a 1,400-h drying period. One end of a cylindrical saturated rock sample was exposed to flowing dry nitrogen gas. The rock sample contained several microfractures oriented transversely to the direction of the outgoing water flux. After 2 days, the average saturation of the rock was above 0.95; after 29 days the average saturation of the sample was approximately 0.70; after 58 days the average saturation was about 0.60. The microfractures appeared to dry before the smaller pores, in agreement with capillary-bundle theory.

7. Effects of ventilation on saturation of drift walls in the exploratory shaft. Eaton and Peterson (1988) analyzed the effects that ventilation could cause on the saturation levels in drift walls in the exploratory shaft facility. These calculations assumed that 10 percent of the construction water was retained in the walls, as indicated by West (1988). The hydrogeologic units were defined by data from borehole USW G-4, and the initial saturation was established by assuming a constant 0.1-mm/yr vertical ground-water flux. A relative humidity of 10 percent at the inside of the drift wall was used. After 4 weeks, drying from ventilation resulted in more water removed from the rock mass than lost to the rock by construction water. At one year, the effect of drying has penetrated approximately 2 m into the undisturbed rock.

8. Ventilation effects on saturation over longer time periods. One- and two-dimensional analyses of drift ventilation effects on rock saturation were performed by Hopkins et al. (1987). The hydrologic stratigraphy used in this study was representative of the TSw2 unit. A one-dimensional calculation of constant ventilation for a period of 100 years indicated that ventilation appreciably reduced saturation levels in the drift wall. The 1-D analyses indicated that moisture removal during cycling ventilation could be reasonably represented by constant ventilation. Two-dimensional simulation of constant ventilation for 20 years resulted in changes in the initial saturation at 15 m into the drift wall. For a 2-D simulation of constant ventilation for 50 years with a subsequent recovery period, the fluid velocity field indicates that advective contaminant transport from a waste canister could be prevented for more than 250 yr. The rates of advective transport are sensitive to the assumed values of flux, which affect the initial saturation in the drift walls, and to the relative humidity. The analyses, which neglected the effects of heat from emplaced waste, indicate that, within a few years, ventilation could remove a volume of water comparable to that lost to the rock mass by construction.

In summary, although large-scale air movement within the deep unsaturated zone at Yucca Mountain has not been observed under natural conditions,

the air movement observed in open boreholes penetrating the upper few hundred meters of the unsaturated zone may suggest that such processes could occur. Appreciable air flow and exchange with the atmosphere would tend to dry the rock matrix and reduce the ground-water flux at the proposed repository horizon. Drying also may result from the ventilation system that will be required during testing and operation. Water vapor will be removed by the ventilation system. This will lead to subsequent decrease of the saturation levels in the rock mass surrounding the walls of the underground facility until closure of the repository. A backfilled exploratory shaft is not expected to become a preferential pathway for gas flow if the air conductivity of the backfill is less than the value expected from using crushed tuff. Study 8.3.1.2.2.6 is intended to investigate naturally occurring and induced gas-phase movement in the unsaturated zone.

### 8.4.3.2.2 Geochemical analyses and data

During construction and operation of both the exploratory shaft facilities and the repository, numerous fluids besides water (such as antifreeze, hydraulic fluid, diesel fuel, and various gases) and materials (such as experimental instrumentation, concrete, and other construction materials) will be introduced into the host rock in varying quantities. The following paragraphs briefly summarize the potential impacts of these materials. The summaries are numbered for ease of cross-referencing.

1. Decision-tree analysis of potential impacts of introduced materials on repository horizon. To evaluate the effects of the fluids and materials that will be used in the ESF, a decision-tree analysis was developed that first collected and tabulated information about the type and the quantity of fluids and materials that were expected to be used (West, 1988). These data were then rearranged to obtain the total mass of a given material or fluid for a specific time of usage, location of the use, and potential for recovery at the conclusion of exploratory shaft site-characterization activities. The data were screened to evaluate potentially deleterious reactions among combinations of fluids and materials. This screening specifically evaluated the conditions for reaction, including such things as quantity, location (specific physical location of each material and fluid), temperature, pressure, and presence of a catalyst. The screening was performed to evaluate whether pairs of materials and fluids could actually react in the ESF environment.

The decision-tree analysis did not identify any materials or pairs of materials whose presence had a significant impact on the repository horizon, and, therefore, no materials were recommended to be prohibited from use. The results of the materials-screening study identified two major categories of materials that could have potentially significant effects: hydrocarbons and solvents. Because most of the materials fell into one of these categories, West (1988) was able to draw conclusions at the category level, thus eliminating the need to analyze the interactions between specific types of hydrocarbons, solvents, or both.

West (1988) indicates that hydrocarbons introduced into the ESF will tend to remain near the ESF, although some mechanisms can be postulated that

would lead to their transport away from the ESF. From a hydrologic perspective, the quantities and effects of organics (oil, grease, etc.) lost at the surface were judged negligible by West (1988). Even if the organics are concentrated, the report indicates that the effects of any of the organics lost on the surface above the repository should not reach the repository for at least 10,000 years because of the immobility of the chemicals. The depth of penetration of the chemicals generally can be approximated by the estimated depth of water penetration (Section 8.4.3.2.1).

Compared with the millions of gallons of water that are proposed for use during site characterization, organic solvents will primarily be present in small localized quantities. The volume of rock affected by solvents will also be small, and the depth of penetration will be minimal. Though not specifically addressed in West (1988), the report suggests that solvents will evaporate, leaving an even smaller amount of solvent to penetrate the rock. West (1988) concludes that the solvents will probably not significantly affect site performance.

West (1988) points out that interactions between hydrocarbons and solvents will tend to lower the viscosity of liquid hydrocarbons, enabling them to be carried deeper into the formation. However, based on hydrologic analyses (Sections 8.4.3.2.1 and 8.4.3.2.2), West (1988) predicts that the depth of penetration will not amount to more than a few centimeters. Again, volatile solvents will gradually evaporate. From the standpoint of the decision-tree analysis, West (1988) concluded that all materials categorized as hydrocarbons or solvents were unlikely to produce any significant impacts if introduced into the ESF, but suggested that these substances be restricted to use at the surface when possible.

2. Effects of biological degradation and transport. The West study (1988) also investigated the potential effects of biological degradation and transport. The study concludes that organic fluids that have been or will be introduced into the repository block appear to be biodegradable and capable of supporting large numbers of microorganisms. The organic matter that may be introduced during ESF construction and operation are expected to biodegrade slowly. West (1988) indicates that microorganisms can exist in the Yucca Mountain environment, but no area has been identified where this constitutes a problem. Although the introduction of organic substances and the presence of suitable water chemistry, along with a source of oxygen (ventilation air), will promote biological activity, the consequences have not been identified as having a detrimental effect. Movement of significant quantities of materials due to microbial activity will probably depend on fluid transport. As discussed in West (1988), the quantities of fluids and the properties of the rock combine to limit the extent of significant effects.

3. Potential effects of the concrete shaft liner on ground-water chemistry. The potential changes in the ground-water chemistry from interactions with the concrete liner for the exploratory shafts were evaluated by Fernandez et al. (1988). They specifically evaluated the effects of leaching alkaline constituents from the concrete liner, and the pH of the pore fluid was estimated to increase to about 13.9 as a result of leached materials. Test results show that after three months of contact between well J-13 ground water and concrete, the only ion concentrations that were significantly

higher than the initial composition of well J-13 water were $Na^+$, $K^+$, $OH^-$, and $SO_4^{--}$. The change in the $OH^-$ concentration changed the pH from 6.9 to 9.9, while the concentration of $Ca^{++}$ decreased during the test. Analysis of the effect of an increase in the $OH^-$ concentration showed that chemical equilibrium between $HCO_3^-$ and $OH^-$ results in an increase in the $CO_3^{--}$ concentration. The increase in $CO_3^{--}$ concentration can result in the formation of a $CaCO_3$ precipitate and a decrease in the $Ca^{++}$ concentration. Analysis also indicated that the formation of precipitates from the interaction of chemicals leached from the shaft liner with ground water would be a localized phenomenon and the precipitates would not travel far from the liner.

In summary, the construction and operation of the exploratory shaft facility are not expected to significantly affect the geochemistry of the potential repository host rock in a manner that could interfere with in situ testing or that could detrimentally impact performance of the site. Small effects may be produced locally near the ESF, but it is highly unlikely that any of the materials currently identified to be used in ESF construction or operations will move far from the site at which these materials are introduced.

### 8.4.3.2.3 Thermal/mechanical analyses and data

This section summarizes the results of selected thermal, structural, and other analyses, as well as the results of some preliminary and prototype experiments. Some of this material serves as background information for discussions in Section 8.4.2.3. The primary purpose of the summaries here is to support the analyses of the potential impacts of site characterization activities on performance objectives (Section 8.4.3.3). The analyses are categorized in general sections of thermal/structural analyses of shafts and drifts and pretest analyses of experiments proposed for the ESF.

#### 8.4.3.2.3.1 Analyses of shafts and drifts

1. Excavation-induced effects on permeability. Changes in rock mass permeability due to stress redistribution and blast damage immediately surrounding a shaft being excavated in a fractured, welded tuff were evaluated by Case and Kelsall (1987). For several of the evaluated conditions, the equivalent permeability of a modified permeability zone (MPZ), averaged over an annulus whose thickness was one shaft radius around the shaft, increased by 15 to 80 times the undisturbed rock-mass permeability. At distances greater than 4 to 5 m from the shaft wall, the disturbed rock mass permeability increased by less than a factor of 2 to 3. At distances greater than 8 m, the disturbed rock mass permeability increased by less than a factor of 2.

An extensive discussion on the adequacy and the assumptions used to develop the MPZ model is given in Case and Kelsall (1987). They concluded that the models developed for the MPZ are conservative in that they overestimate the change in the hydraulic conductivity of the rock mass surrounding the shaft wall. A recent study that used the STEALTH explicit

finite-difference code on the CAVS jointed rock constitutive model to evaluate the response of an orthogonal fracture system surrounding a circular shaft (Dial et al., 1988). The study concluded that, qualitatively, the excavation-induced joint response predicted by STEALTH was similar to the joint response predicted with an analytic model used by Kelsall et al., (1982). This conclusion suggests that simple analytic models are appropriate for estimating excavation-induced joint response. Because Case and Kelsall (1987) used a technique identical to the one presented by Kelsall et al., (1982), the MPZ model developed for welded tuff by Case and Kelsall (1987) is also appropriate for estimating excavation-induced joint responses.

The MPZ model implicitly includes the effects of liner removal. This model assumes no support to the shaft wall from the shaft liner, because the assumption is made that the radial stress acting at the shaft wall is zero. This assumption will tend to maximize the change in the fracture apertures, which will maximize the permeability. Further, to increase the fracture aperture, it is assumed that "onionskin" fractures normal to the radial direction will open, and are the predominant factor in the alteration of permeability. Under elastic conditions, the radial stress will decrease to zero assuming no support at the shaft wall, while the tangential or boundary stress will increase and close a system of "radial" fractures. Since permeability depends on changes in aperture for "onionskin" and "radial" fractures which will close and open respectively, it is conservative to assume that permeability is only affected by radial stress relief. Further, it is conservative to neglect the effects of support, which would reduce the degrees of stress relaxation, and the degree to which "onionskin" fractures would open. Although no analysis has been conducted to evaluate the coupled effects of fluids on the distribution and magnitudes of the circumferential and radial stresses, such effects will likely be small if the volumes of fluids are small (Rice and Cleary, 1976).

Evidence regarding changes in permeability around a tunnel in granitic rock was obtained from the macropermeability test at Stripa, Sweden (Case and Kelsall, 1987). Radial hydraulic gradients were measured for radial flow occurring toward the room. A steep hydraulic gradient, which may be interpreted as a zone of reduced hydraulic boundary stress due to the elastic response of the rock, results in an enhanced hydraulic conductivity for a "radial" system of fractures.

From the preceding discussion, it was concluded that the effect of liner removal has adequately been addressed by the current MPZ model.

To assess the preclosure (up to 100 yr) stability of underground excavations at Yucca Mountain, Ehgartner and Kalinski (1988) have summarized 14 analyses by 10 different investigators. Although the principal purpose of these analyses was to examine various aspects of structural stability in the proposed repository, a basis is also provided for preliminary assessment of the potential for thermal and mechanical interactions between the ESF shafts, between the shafts and drifts, and between the ESF drifts and the proposed repository main drifts and access drifts. Thus, the results of these analyses are discussed briefly here.

2. Stability of unlined shaft. Hustrulid (1984a) modeled circular shaft in the Calico Hills and lower units using both elastic and plastic

behavior. A 10.8 MPa horizontal in situ stress was applied to the shaft in a calculation assuming axisymmetric conditions about the shaft centerline. Under wet conditions, the concrete liner thickness necessary to maintain a factor of safety of 1.5 was determined to be 0.41 m, while no liner would be required for dry conditions with the strength reduction factor equal to 2.0. A 14-ft-diameter concrete-lined shaft in the Calico Hills formation was also analyzed by Hustrulid (1984b). In situ stress conditions of 5 MPa minimum horizontal principal stress were modeled. The maximum component of horizontal in situ stress was 5 and 10 MPa for the analyses. When the model took into account rock-mass properties, failure was predicted to occur around the shaft to a distance of 0.3 m in the rock mass in the case of equal components of horizontal in situ stress. For a ratio of 2 to 1 in the in situ horizontal stresses, fracturing was estimated to extend 0.6 m into the rock mass perpendicular to the direction of maximum horizontal stress. Thus, the study concluded that no major difficulties would be expected in constructing a shaft in the Calico Hills formation and that effects, such as fracturing, would not be expected to extend far into the wall rock. Improved conditions would be expected in the Topopah Spring tuff (TSw2) because of the larger compressive strength and the lower in situ stresses. The methods used by Hustrulid (1984a) in this analysis were shown to be conservative based on a comparison between predicted and measured liner pressures in a concrete lined shaft at Mt. Taylor (Grants, NM). Considerable differences were found between the theoretical analysis and field measurements. The theoretical analyses appear to overestimate the pressures and are therefore considered very conservative.

3. Thermal effects on stability. St. John (1987a) analyzed 6-m-diameter concrete lined repository access shafts at two different locations at repository depths. Elastic analyses were performed for a shaft located (1) centrally in the repository within a 200-m-diameter shaft pillar and (2) 100 m from the edge of a waste panel. The analyses were time dependent and considered the thermally induced load up to 100 yr after waste emplacement. The thermal load was based on an areal power density (APD) of 57 kW/acre. The stresses around the two shafts showed slight differences, but in neither instance was the rock mass surrounding the shaft fractured because of the in situ or thermally induced loading. The liner hoop stresses were low in comparison to the compressive strength of typical concrete. The concrete shaft liner was predicted to have approximately 4.3 MPa of tensile stress induced along its axis at the repository horizon after waste emplacement. This stress could produce horizontal cracks in the liner. However, the study concluded that there was no evidence that such cracking would be detrimental to the performance (stability) of the liner or the performance of the site.

4. Predictions of thermal stresses and displacements. Unventilated rectangular drifts in the Topopah Spring Member and Calico Hills unit were analyzed by Johnson (1981) for vertical emplacement. A ubiquitous joint model was used to determine stresses and displacements at times up to 100 yr after waste emplacement. Areal power densities (APD) of 75 and 100 kW/acre were used, with but both resulting in nearly the same stress levels near the drift. For both APDs, intact failure was predicted only at the corners of the drifts; in neither instance did it extend more than 1 m into the rock mass. Johnstone et al. (1984) also reported results of an analysis of rectangular emplacement drifts in the Topopah Spring member, Calico Hills

unit, and in lower rock units to establish the maximum APD for each formation. These calculations were later documented more fully by Johnson and Bauer (1987). The results of their analysis of an unventilated vertical emplacement drift using the ubiquitous-joint model (Thomas, 1980; Johnson and Thomas, 1983) for times up to 110 years were reported assuming average and limiting properties. The limiting properties were taken as either plus or minus two standard deviations from average values; the sign was determined on a worst-case basis. No matrix fracturing was predicted around the Topopah Spring drift for the waste emplacement period for either the average or limiting property cases. Limited amounts of vertical joint slip were predicted in the sidewalls of the drift out to approximately 6 m from the wall, both at and after waste emplacement. As supported by the evidence from G-Tunnel, however, joint slippage was predicted to have no consequence on drift stability. The ubiquitous joint model predicted a slightly larger slip region for the rock surrounding a G-Tunnel (Grouse Canyon Formation) drift than for the repository drifts, but little joint displacement was evident in the mining evaluation drift or other drifts at G-Tunnel except within 1 to 2 m of the opening (Zimmerman et al., 1988). These calculations were repeated by Thomas (1987) using a different jointed rock mass model (Thomas, 1982). Two-dimensional analyses of rectangular shaped, unventilated vertical emplacement drifts in both the Topopah Spring member and Calico Hills unit were performed. Both average and limiting rock mass properties were used (as in the analysis of Johnson and Bauer, 1987) with an assumed 57 kW/acre APD. No potential for intact rock failure was noted in the drifts for either the average or limiting properties cases over the 100 yr interval analyzed. Joint slip on the order of 1 mm within 3 m of the drift walls was noted.

5. Effects of drift shape and pillar width on stability. Hill (1985) analyzed the structural stability of the conceptual design of the ESF main test level in the Topopah Spring member. The analysis had two parts, a three-dimensional model of the ESF and a two-dimensional parametric study of two drifts separated by a pillar. Two drift shapes (rectangular and arched roof) and two pillar widths (6 and 2 m) were analyzed. The two-dimensional analyses used both elastic and inelastic joint material models (Thomas, 1982); the results from each were similar. The three-dimensional calculations were completed using a linear elastic model. For the two-dimensional analyses, the lowest safety factor against intact rock failure near a drift wall was 3.0. The wide versus narrow pillar analysis, showed that drifts had to be closer than one-half drift diameter before the stresses at a drift wall were significantly influenced by the presence of the second drift.

6. Effect of porosity on rock strength. SNL (1987; Appendix I) performed an elastic analysis of arched drifts by varying the thermal and thermal/mechanical properties of the Topopah Spring Member as a function of porosity in a thermomechanical model of the horizontal and vertical emplacement drifts 100 yr after waste emplacement. An areal power density of 57 kW/acre was used. The study concluded that, for the TSw2 formation with expected ranges in porosity of 9 to 15 percent, the drifts were stable and the drift temperatures were not excessive. Fracturing at the crown of the vertical emplacement drift was predicted to occur only if the rock porosity exceeded 21 percent. The low lithophysal layers within TSw1 have an expected porosity of 14 percent, and the high lithophysal layers within TSw1 have an expected porosity of 35 percent. For high porosity layers, no failure was

predicted for a horizontal emplacement drift. However, stresses in the drift crown would slightly exceed the rock mass strength for the vertical emplacement case. These stresses imply the possibility of localized failure (fracturing) of the crown rock that could be stabilized with ground support.

7. Effects of rock bolts on stresses near emplacement drifts. The effect of rock bolting on the stresses near horizontal and vertical emplacement drifts was analyzed by St. John (1987b). Various in situ stress conditions were assumed, ranging from uniaxial to lithostatic. A damage region was modeled around the drift to simulate the effects of blasting during excavation, and rock bolts were inserted in the crown region. The calculated stresses in the rock bolts were approximately one-half the allowable strength of the rock bolts. The rock bolts had a negligible effect on drift stresses and deformation compared with the analyses of an unsupported drift.

8. Stresses developed at an unventilated drift intersection. St. John (1987c) analyzed the intersection of an emplacement drift with a panel access drift using an areal power density of 57 kW/acre. The three-dimensional elastic calculations used thermally induced stresses to examine an unventilated intersection in the Topopah Spring Member. Stresses in the crown of the intersection reached approximately 23 MPa 50 years after emplacement. Tensile stresses approaching 9 MPa were predicted in the drift wall at the intersection, and were reduced to zero at 3 m into the drift wall. The tensile stresses in the field will likely be less severe than those predicted because of the presence of low-angle (i.e., nearly horizontal) fractures.

9. Thermal stresses on arched emplacement drifts. The results of two-dimensional finite element and boundary element calculations for arched emplacement drifts under thermal loading to 100 yr after emplacement were reported by St. John (1987a). The calculations assumed a 57 kW/acre areal power density. Both vertical and horizontal emplacement drifts were analyzed assuming either continuously ventilated and unventilated drift conditions. Using average rock mass properties, the highest stresses were noted at the drift crown 100 years after waste emplacement. The magnitudes of the principal stresses in the drift crown ranged from 31 to 36 MPa for the horizontal emplacement drift, depending on the drift ventilation assumed. Higher stresses occurred for the unventilated drift condition. The vertical emplacement drift had crown stresses ranging from 13 to 54 MPa for ventilated and unventilated conditions, respectively.

10. Sensitivity study for drift failure. Ehgartner (1987) investigated specific parameter sensitivities and calculated the probability of failure of an arched roof horizontal emplacement drift using a probabilistic technique. Input parameters were varied both individually and jointly to determine the effect on the drift 50 yr after waste emplacement, assuming a 57 kW/acre areal power density. The results indicated that changes in rock strength and modulus in the Topopah Spring had a greater effect on factors of safety than did the other parameters, but in no case was failure of the rock mass predicted. The probability of encountering poor ground conditions that may need supplemental ground support for the horizontal emplacement drift was estimated to be approximately 20 percent.

11. Stability of panel access drifts. Panel access drift stability at various locations and standoff distances from the emplaced waste in the

Topopah Spring Member was examined by St. John and Mitchell (1987). The elastic two-dimensional calculations considered an unventilated horizontal emplacement 50 years after emplacement using an APD of 57 kW/acre. Arched shaped drifts were analyzed at locations in the central and outer edges of the repository, assuming near lithostatic in situ stress field. No rock mass stability problems were identified at any of the potential locations.

12. Estimates of blast damage to the exploratory shaft facility pad. The ESF pad preparation will involve some blasting to remove surface rock and to produce a level pad for construction activities. The damage that these blasting operations will induce to the remaining pad can be estimated using empirical data on blast damage. Two approaches can be used: One is to examine the fracturing around a (confined) blast hole; the other is to estimate peak particle velocity levels around the blast and correlate these levels with the strength of the tuff to estimate the extent of the damage.

To estimate the damage, the explosive type and blast hole diameter must be known. Although the blasting design has not yet been chosen, blasting operations are standard and should be fairly uniform from design to design. For this estimate, 6-in.-diameter blast holes and AN-FO blasting agents will be assumed. The actual design will depend on the size and depth of the cut, but the above estimate should be representative.

Using the first damage-estimate approach of fracturing around a blast hole, the results from four studies (Cattermole and Hanson, 1962; Olson et al., 1973; Siskind et al., 1973; Siskind and Fumanti, 1974) have shown that the radius of damage around a confined explosive charge varies from 15 to 30 charge radii. For a 6-in.-diameter blast hole, the expected damage would extend about 7.5 ft out from the blast holes. These studies were in granite, shale, and tuff and used four different explosives, including AN-FO. The study in tuff also listed a major crack-damage radius of 10 to 12 charge radii. The data for major crack damage in tuff suggest that this type of major damage may occur out to 3 ft from the blast holes. Even these limited damage ranges could probably be reduced by not confining the charges and by using standard controlled-blasting techniques.

Using the second damage-estimate approach of peak particle velocity, a study in shale showed the peak particle velocity can be estimated using only the blast-hole loading density and the range from the blast (Redpath and Ricketts, 1987). Using this and a tuff strength value of 25,000 lb/in.$^2$ (170 MPa) (Chapter 2) results in a damage range of 8.5 ft for 6-in. blast holes using AN-FO. This value is fairly consistent with the previous estimate using fracturing around a blast hole. This estimate uses a well-established linear relation between stress and particle velocity (Rinehart, 1974) that has been shown to apply to very high stress levels (millions of lb/in.$^2$).

Thus, on the basis of two independent, empirical approaches, it appears that blasting damage to the ESF pad may occur 7.5 to 8.5 ft from the blast, with major cracking out to 3 ft from the blast. This situation can be even further improved (1) by using standard controlled-blasting methods, (2) by using multiple cuts with smaller blast-hole diameters (since damage is strongly related to blast-hole diameter), (3) by slanting the blast holes to reduce confinement at the bottoms of the holes, and (4) by using variable

explosive columns to reduce the loading density near the critical damage areas.

### 8.4.3.2.3.2 Analysis of in situ experiments

The following discussion describes analyses that have been done on past in situ experiments or those prepared to predict the potential thermal and mechanical effects of some of the ESF in situ tests.

1. Analyses of effects of the shaft convergence, demonstration breakout rooms, and sequential drift mining experiments. Costin and Bauer (1988) describe analyses conducted in support of the excavation investigations planned for the ESF. Preliminary analyses of the shaft convergence, demonstration breakout rooms (DBR) and sequential drift mining experiments have been completed. In the shaft convergence analyses, the stress and displacement histories of the rock surrounding the shaft were determined as the shaft was mined through three different strata. The concrete lining was assumed to be emplaced 10 m behind the front face of the shaft. The calculated maximum convergence of the shaft is on the order of 2 mm. All the predicted displacements resulting from excavation were found to be quite small. The stress-altered region (defined as the region where the stresses differ from the initial in situ values by more than 10 percent) extended radially from the shaft centerline for approximately four shaft diameters (15 m). Stresses differ from the in situ values by less than 1 percent at approximately 30 m (7.5 shaft diameters) from the shaft centerline. The horizontal stresses beyond 5 m from the shaft bottom differ from the in situ stresses by less than 10 percent. Calculated stresses in the concrete liner were very low (less than 5 percent of the unconfined compressive strength of normal concrete).

The purpose of the DBR analysis was to estimate the magnitudes of the drift convergence, potential stresses in the rock bolts, and the extent of the zone of stress relaxation near the DBRs (Costin and Bauer, 1988). Only elastic analyses were performed. The analyzed drifts were assumed to have been excavated at depths of 160 and 366 m with a nominal length of 18 m. Drifts with no damage and drifts with an assumed damage zone extending 1.0 m into the rock mass around the excavation were analyzed. The damaged rock around the drifts was modeled by reducing the elastic modulus of the rock by 50 percent in the damaged zone. Similar results were predicted for drifts at the 160 m and the 366 m levels. If no damage zone was assumed, the vertical compressive stress increased 100 to 200 percent near the room wall, but was only 10 percent greater than the in situ stress at a distance of 1.2 room diameters (6.1 m). Horizontal stresses differed by less than 10 percent from the in situ values at distances greater than 1.6 room diameters from the drift. The maximum vertical displacements in the roof and floor were predicted to be approximately 3.5 mm. Horizontal displacements were much less, averaging less than 0.5 mm. The effect of including a 1.0-m-thick damage zone around the drift, either at the 160 m or 366 m level, was to transfer the high stresses around the opening to the undamaged rock region. The maximum displacements near the drift also increased from 2.5 mm in the upper DBR with no damage zone to 3.0 mm with a damage zone. In the presence

of a damage zone, the results resemble the results that would be expected for a slightly larger drift.

The analysis of the sequential drift mining experiment assumed that the drifts would be mined at a depth of 320 m. Two drifts assumed to be 4.6 m by 4.6 m high and having a center to center separation of 19.2 m were modeled (Costin and Bauer, 1988). The drifts were assumed to be long enough that plane strain conditions would exist near the center, and, thus, a two-dimensional plane strain analysis would be sufficient to estimate the displacements and stresses around the drifts and to determine whether the drifts were sufficiently separated to preclude interference between the measurement drift and the instrument drift. Analyses were performed with and without a blast damaged zone that was assumed to extend 1.0 m into the rock mass surrounding the excavations. At the time of the analysis, only one access drift was planned, but the current proposal includes an access drift on both sides of the experiment drift. Even so, the analyses provide a good estimate of the stress-altered region around the drifts and the expected displacements that would be measured in the pillar between the instrumented experiment and an access drift. Following excavation of the instrumentation drift, the horizontal and vertical displacements in the region where the experiment drift was to be excavated were found to be on the order of 0.1 mm. The change in horizontal displacements near the experiment drift after excavation ranged from 0.4 mm near the drift wall to 0.1 mm at one drift diameter from the wall. The change in vertical displacement ranged from 2.4 mm in the crown of the drift to less than 0.6 mm at one drift diameter in any direction. The total maximum convergence of the experimental drift was 0.38 mm horizontally and 5.92 mm vertically for drifts with damage zones. For drifts with no damage zone assumed, the horizontal and vertical convergence was 0.07 mm and 4.55 mm, respectively. The horizontal stresses around the opening ranged from the in situ stress (1.9 MPa) to a maximum compressive stress in the crown of 2.4 MPa. Beyond one drift diameter from the opening, the horizontal stress was essentially the in situ stress except in the pillar region directly between the two drifts where the horizontal stress increased to 2.4 MPa. The maximum vertical compressive stress at the midheight of the drift wall on the pillar side was 11.8 MPa (compared with an in situ stress of 7.5 MPa). At a distance of 1/2 drift diameter from the walls and one drift diameter from the floor and roof, the vertical stresses were within 10 percent of the applied in situ stress.

2. Simulation of effects of G-Tunnel heated block experiment. A numerical simulation of the G-Tunnel heated block experiment conducted by Zimmerman et al. (1986a) was reported by Costin and Chen (1988). The analysis simulated both the mechanical and thermomechanical loading portions of the experiment using the compliant joint model (Chen, 1987). The results of the calculations were compared with those of the experiment to demonstrate a capability to model the behavior of a rock mass subjected to thermal and mechanical loads. Both the results of the calculations and the experiment indicate that the rock beyond 8 m from the edges of the block is not significantly disturbed.

3. Analyses of G-Tunnel small-diameter heater experiment. Detailed analyses of the G-Tunnel small-diameter heater experiments (Zimmerman et al., 1986b) were reported by Blanford et al. (1987). Three experiments were conducted in both welded and nonwelded tuffs, using small-diameter (102 mm)

heaters. For two experiments, the heater was oriented vertically in fractured welded tuff and in unfractured welded tuff. The major focus of the experiments was on evaluation of numerical model applications, emphasizing thermal properties. The secondary focus was on hydrothermal measurements and evaluations. The results show good agreement with the experiment and demonstrate that heating of the rock would not extend more than 1 m below and more than 2 m radially from the heater operating at maximum power (1,200 W) for 32 days.

4. Analyses to establish thermal zone influence. Pretest analyses of the ESF canister scale heater experiment, the heated room experiment, and the thermal stress test have been conducted by Bauer et al. (1988). The analysis of the canister scale heater test was performed to determine the heater power history required to satisfy the experimental objectives of heating a large volume of rock to temperatures above 200°C so that thermomechanical models could be verified against the experimental data. Current results indicate that temperatures will be elevated above 200°C out to 1.0 m from the heater and will be above ambient out to a distance of 15 m radially from the heater and 20 m from the emplacement drift wall along the axis of the heater after 30 months of operation.

The heated room experiment consists of a central experiment drift with two parallel access/instrumentation drifts constructed on either side of the main drift. Heaters will be emplaced in the pillars between the drifts so that the central experiment drift is heated along the central portion of its length. Preliminary analyses indicate that after 40 months of heating at 100 kW of heater power, temperatures range from 240°C near the heaters to within 5°C of ambient just beyond the access drifts. The zone of thermally disturbed rock (temperature greater than 5°C above ambient) extends approximately 30 m above and 25 m below the floor of the experimental drift. On the main test level, the presence of the access drifts which are assumed to be ventilated and remain at constant temperature, retards the thermal disturbance so that it does not reach beyond the edge of the access drifts (which are 20 m, center to center, from the experiment drift).

The thermal stress test represents an effort to examine rock mass behavior under large thermally induced stresses. It is intended that heating will be rapid and that the experiment will last only approximately 3 months. According to the proposed plan, two rows of heaters will be installed a short distance to either side of the centerline of the roof of a drift. Preliminary thermal analyses show that after 90 days of operation, the thermally disturbed zone will extend approximately 15 m vertically above and 1 m below the floor of the drift. The zone of heated rock will also extend approximately 8 m from the drift walls.

On the basis of these analyses, the planned minimum separation distance of 30 m between ESF and waste emplacement panels appear adequate. Both thermal and mechanical effects on the rock at this distance appear to be insignificant.

8.4.3.2.4 Design features that may contribute to performance

Postclosure design Issue 1.11 (configuration of underground facilities, Section 8.3.2.2) provides the mechanism for identifying repository design characteristics and configurations important to the evaluation of compliance with 10 CFR 60.133 and for incorporating postclosure performance concerns into the design. The rest of this section is an itemized discussion of some of the design features that may be important in discussing the total-system performance objective and the three subsystem performance objectives. The items discussed are design features or considerations related to site characterization activities that might contribute to performance (primarily postclosure) or aid in mitigating potential deleterious impacts to performance from site characterization activities. The items discussed do not, however, completely describe the design features that may contribute to performance. These design considerations generally address the additional design criteria of 10 CFR 60.133, 60.134, and 60.135.

1. Separation of ESF tests from potential emplacement drifts. The ESF is designed to maintain a minimum lateral separation distance from potential waste emplacement panels. The core area for testing within the ESF is separated by a minimum distance of 30 m (Section 8.4.2.2). Because unsaturated flow within the repository horizon is hypothesized to be primarily vertical, this separation distance will help prevent the ESF from becoming a preferential pathway for radionuclide transport from waste emplacement. This separation will also prevent water used in testing activities from reaching emplaced waste containers.

2. Control of drainage direction. The ESF is designed to drain water used in ESF construction and testing toward ES-1 (Section 8.4.2.2). This design feature will inhibit water from the ESF from moving into waste emplacement panels. The locations of the exploratory shafts have been selected to significantly reduce the potential for water inflow and thereby increase confidence that sealing components can meet their performance requirements.

3. Low flood potential. The exploratory shafts have been located and collared in bedrock where flooding and erosion potential is small (Sections 8.4.3.3.4 and 8.4.2.2). This should limit the potential for shafts to serve as preferential pathways for water from the surface.

4. Location and number of boreholes. Borehole drilling will be coordinated with repository design to locate boreholes, to the extent practical, in pillars (Section 8.4.2.1). This will allow a standoff distance from waste canisters and help prevent the boreholes from becoming preferential pathways for potential radionuclide movement. In addition, statistical methods will be used in planning the boreholes in order to limit the number.

5. ESF test location. The ESF will be designed with sufficient flexibility to locate in situ tests where they will have as high a likelihood of success as possible.

6. Control of water use. The amount of water introduced to the site will be controlled. The water usage will be limited to the extent practicable and will be tagged with tracers to allow detection (Section 8.4.2).

Many of the boreholes will be drilled dry to prevent water intrusion into the rock mass (see Section 8.4.2.1). Strict water controls will be used during drill-and-blast operations.

7. Limit blast damage. The openings in the ESF will incorporate excavation methods that will limit the potential for the surrounding rock mass becoming a preferential pathway. Smooth-wall blasting techniques will be used.

8. Water removal by ventilation systems. The ESF will be ventilated. As described in 8.4.3.2.1, ventilation can remove a substantial amount of water; within a few years, the volume of water removed is estimated to be comparable to the volume of water added to the rock during ESF construction testing.

9. Waste package containment. The waste canisters will be designed to have substantially complete containment for a period of at least 300 years.

10. Use of seals. Exploratory boreholes that represent potential pathways to the accessible environment and the exploratory shafts will be sealed (Section 8.3.3) to limit the potential for them to serve as preferential pathways for flooding events, increased percolation, transport of radionuclides, or gas-phase transport.

11. Avoid surface-water impoundment. Surface activities, such as the construction of spoils piles, will be conducted in a manner that will avoid the creation of surface-water impoundments that could impact postclosure performance.

12. Use of air gaps. An air gap will be maintained to the extent practical between the waste canisters and the emplacement-hole wall to inhibit water movement into the opening and thus inhibit corrosion.

13. Use of controlled blasting. Controlled blasting will be used in the construction of the exploratory shafts to limit the amount of blast-induced changes in permeability to the surrounding rock (Section 8.4.2.3.4.4 and Section 8.4.3.2.3, Item 1). The design of seals to be used in the exploratory shaft and underground facility inherently incorporates both the effects of blast damage and stress redistribution accompanying excavation. The model of Case and Kelsall (1987) provides a conservative estimate of the change in the permeability of the modified permeability zone (MPZ) surrounding the exploratory shafts. These permeability modifications are considered in Fernandez et al. (1988), where it is concluded that the MPZ does not significantly enhance radionuclide release for several extreme disruptive scenarios. The use of controlled blasting is expected to result in permeability changes that are consistent with shaft sealing concepts and performance allocation; reduce uncertainties in predicting seal performance; and reduce limitations in emplacing sealing components.

14. Removable shaft liner. The shaft liner is designed to be removable. Techniques to remove the liner are discussed in Fernandez et al. (1988). Maintaining the capability to remove the liner reduces limitations associated with emplacing seal components. Liner removal could enhance seal component performance by improving drainage from the base of the shaft.

### 8.4.3.2.5 Potential impacts to current site conditions from site characterization activities

This section uses the information presented in Sections 8.4.3.2.1 through 8.4.3.2.4 to determine which hydrological, geochemical, and thermal/mechanical disturbances from site characterization activities are transient and which disturbances will be long-lasting or permanent. The transient effects are those effects that will no longer be significant after permanent closure and for that reason would not be expected to affect postclosure performance. The long-lasting or permanent disturbances could potentially affect postclosure performance and will be evaluated (1) with respect to the total-system-release performance objective in Section 8.4.3.3.1 and (2) with respect to the three subsystem performance objectives addressing container lifetime, EBS release rate, and ground-water travel time in Sections 8.4.3.3.2, 8.4.3.3.3, and 8.4.3.3.4, respectively. This section evaluates the potential impacts to current site conditions; Section 8.4.3.3.1 addresses whether the permanent changes resulting from site characterization activities discussed in this section could preclude the site from meeting the performance objectives, given the occurrence of future events and processes.

The types of penetrations or disturbances to the site have been categorized in Section 8.4.2 for both surface-based and ESF-related activities. For the surface-based testing and construction activities, the categories are (1) drilling (shallow and deep dry holes, coreholes, and saturated-zone boreholes); (2) surface site characterization activities (e.g., pavements, trenches, and ponding tests); and (3) construction or site-preparation activities (e.g., roads, drillpads, dust control, installation of utility lines). For the ESF-related activities the categories are construction of the shafts, construction of drifts and testing alcoves, and testing (within the shaft, breakout areas,and the main underground facility). Many of these penetrations or disturbances will affect the hydrologic, geochemical, and thermal/mechanical conditions of the site in a similar manner because they disturb the site in similar ways (e.g., similar construction methods and similar conditions under which fluids and materials are introduced). In this summary, the categories of site characterization activities are grouped according to the type of disturbance as follows:

1. Surface-related activities (pavements, trenches, ponding tests, road construction and use, dust control, drillpad construction, and seismic surveys).

2. Drilling activities (shallow and deep dry holes, coreholes, saturated-zone boreholes, and underground boreholes).

3. Exploratory shaft construction.

4. Underground construction of exploratory shaft facility drifts and testing alcoves.

5. Exploratory shaft facility testing activities.

8.4.3.2.5.1 Potential impacts to the site from surface-related activities

The potential impacts to the site from surface-related activities are evaluated in this section. The hydrologic, geochemical, and thermal/mechanical analyses and data that provide the basis for evaluating the potential impacts resulting from surface-related activities are summarized in the previous sections. The surface-related activities are discussed in Section 8.4.2 and include pavements, trenches, ponding tests, road construction and use, dust control, drillpad construction, and seismic surveys. Evaluations of potential impacts resulting from hydrological, geochemical, and thermal/ mechanical disturbances occurring as a part of site characterization activities will be presented in the following paragraphs.

Potential impacts from hydrologic disturbances

Hydrologic disturbances can potentially affect the site in a number of important ways; for example, the site can be affected by altering the amount and distribution of flux at the repository horizon and by changing the hydrologic characteristics of the unsaturated zone. Section 8.4.3.2.1 presents analyses and data that address the potential impacts of altering hydrologic conditions and properties in the unsaturated zone at Yucca Mountain.

Section 8.4.2.1 describes the surface-related activities that will add water to the surface at Yucca Mountain. The water pressures will be low (generally centimeters of head), and the contact times will generally be short. The data and analyses presented in Section 8.4.3.2.1.1 indicate that water introduced to the surface of the site at low pressures for short times (similar to precipitation events) will not generally produce measurable changes to the moisture content below a depth of approximately 10 m. Additionally, the analyses in Section 8.4.3.2.1.2 (e.g., items 10 and 12 in that section) indicate that any water added to the site will equilibrate within a few weeks to months. Changes to net infiltration, and subsequent percolation flux at the repository level, are thus expected to be insignificant. Most of the water introduced to the site will be for dust control and will be introduced to the surface at low heads for short contact times. Other surface-related site activities introducing water will also use low heads and short contact times. Therefore, adding water to the site from surface-related activities is not expected to result in permanent changes to the flux at the repository horizon.

Permanent changes to the physical topography of the site from surface-related activities were also considered in evaluating the potential to alter the percolation flux. Also investigated were potential impacts to percolation flux at the repository horizon if water was ponded at the surface, as for example, might occur if the spoils pile were inappropriately located where it might cause water ponding. To be conservative, the analysis in Section 8.4.3.2.1.1 assumed that the water would be ponded over a highly permeable zone at Yucca Mountain (e.g., a permeable fault zone). A column of water 10 m high was used as the pressure head and was allowed to stand for over two days. The results indicate no change to the water velocities or percolation flux at the repository level for at least 1,000 years and only a factor of 2 change in the water velocities at the repository level between

10,000 and 100,000 years. Given current site conditions, therefore, surface-related activities are not expected to provide the potential to significantly alter the flux at the repository level.

Hydrologic disturbances could potentially result in changes to the site by altering the moisture content (which changes the value of the unsaturated hydraulic conductivity). As discussed previously, changes to the moisture content caused by performing surface-related site characterization activities are expected to be transient and are not likely to permanently affect the unsaturated hydraulic conductivity of the near-surface material.

Surface-related activities are not expected to lead to new preferential pathways because the activities are limited to the surface or to within a few meters of the surface.

Potential impacts from geochemical disturbances

Fluids and materials similar to those introduced to the ESF (West, 1988) will be introduced to the surface, as described in Section 8.4.2.1. West (1988) estimates that the depth of penetration of materials that are not soluble in water will generally not penetrate more than approximately the penetration depth of the water introduced, which is approximately 10 m. The analyses presented in Section 8.4.3.2.1.2 indicate that water takes tens to hundreds of thousands of years to move from the surface to the repository horizon. Any chemicals left in the surficial material from surface-related activities are not expected to significantly impact site performance during the period of concern for the total-system-release postclosure objective. Therefore, there are no geochemical disturbances that could be expected to lead to impacts on site conditions during the postclosure period of interest.

Potential impacts from thermal/mechanical disturbances

No surface-related activities will involve significantly increased temperatures at depth. The mechanical disturbances to the stress conditions of the site, and thus the fracture apertures and hydraulic conductivity, are expected to be limited to within a few meters of the surface. Mechanical disturbances from preparing the pad for the exploratory shaft would be similarly limited in extent. Because the repository is more than 200 m below the surface, these potential changes to the hydraulic conductivity of the surficial material are not expected to significantly impact the performance of the site.

8.4.3.2.5.2 Potential impacts to the site from drilling activities

The potential transient and permanent impacts to the site from drilling activities are evaluated in this section. The surface-based activities discussed in Section 8.4.2.1.1 categorized the drilling activities by drilling methodology: dry drilling, drilling with mud, and drilling with air foam. For the dry drilling method, the activities were also categorized by depth of the hole. The following evaluation of the potential impacts to the site from drilling activities categorizes the information by shallow borings drilled

dry, deep borings drilled dry, geologic core holes drilled with water containing a polymer, and saturated zone boreholes drilled with air foam.

Evaluations of potential impacts on the site resulting from hydrological, geochemical, and thermal/mechanical disturbances from drilling activities are discussed in this section. The detailed summaries of the hydrologic, geochemical, and thermal/mechanical analyses and data discussed earlier in Section 8.4.3.2 provide the basis for evaluating the impacts.

Shallow borings drilled dry

The shallow borings drilled using dry drilling methods include neutron access holes, seismic shotholes, and large and small rain-simulation holes. The current maximum depth of holes included in this category is about 60 m. The details of these drilling activities are discussed in Section 8.4.2.1.1.

Potential impacts from hydrologic disturbances

Hydrologic disturbances could potentially affect the site performance by increasing the flux at the repository horizon. As discussed in Section 8.4.2.1, an element of construction control for site characterization is the selection of dry drilling and coring methods for some site characterization activities. This drilling method was selected instead of drilling using water to decrease both the potential for fluids affecting cutting samples and in situ hydraulic conditions and the potential for losing fluid to the unsaturated zone. Dry drilling will use compressed air at pressures of about 2 bars to cool the drill bit and carry away drilling cuttings. Analyses discussed in Section 8.4.3.2.1.1 indicate that the effects of drilling with air on the air pressure in the rock are dissipated relatively quickly and that near-initial conditions are reestablished in about one day. The matrix saturation is very slightly decreased because of the movement of air into and out of the matrix during drilling. These changes are, however, small and transient. Any permanent changes to the net infiltration and the percolation flux at the repository level from shallow borings would be insignificant because of the sealing of the boreholes.

Testing performed in the rain-simulation holes will include water-ponding experiments. These experiments will use small heads of water and short contact times between the water and the rock (days). Data and analyses discussed in Section 8.4.3.2.1.1 indicate that water contacting rock surfaces at low pressure and for short times will not significantly change the moisture content in the rock at distances beyond 10 m. Adding a small amount of water to the site from these tests is expected to cause only short duration changes in moisture conditions in the proximity of the borehole. This increase in moisture should be redistributed within the matrix and any water introduced into fractures should be imbibed into the matrix within a few meters to tens of meters. There are no expected permanent changes to percolation flux at the repository horizon because of the sealing of the holes.

Potential impacts from geochemical disturbances

Changes in geochemistry could potentially affect the site performance by altering the environment near waste emplacement, reducing the capability of

the tuff to retard transport of radionuclides, or affecting the flux of water. Some of the fluids and materials discussed by West (1988) for the ESF construction will be used during dry drilling of shallow boreholes. For example, a small amount of oil may be introduced into the rock wall during dry drilling. West (1988) estimates that the depth of penetration will generally be a few centimeters and that no significant interactions of oil with other materials should occur. Casings and grouts may be used in some of the boreholes. Fernandez et al. (1988) analyzed the potential geochemical changes from the interaction of grouts with ground water. They concluded that some chemicals may form precipitates, but the effect would be localized and the chemicals would not be transported far from the wall.

Even though these are permanent changes to the geochemistry of the site, they are localized effects that should remain near drillholes. These changes are not expected to affect the environment near the waste package, reduce the capability of the tuff to retard transport of radionuclides, or significantly affect either the water flux at the repository horizon or the postclosure performance.

Potential impacts from thermal/mechanical disturbances

Thermal and mechanical disturbances could potentially affect the site performance by altering the hydraulic conductivity of the rock mass. They could also potentially affect the water flux at the repository horizon by creating preferential pathways. The air drilling of shallow boreholes may result in a temporary increase in the temperature of the rock for a short time. If the temperature of the rock increases to above the boiling point of water, the moisture content of the rock matrix may change slightly. This temperature increase and moisture change should be a temporary effect, and because of the distance of at least 100 m from waste-emplacement areas, the change should not affect the waste-package environment or postclosure performance.

Mechanical disturbances to fracture apertures and hydraulic conductivity from dry drilling are expected to be limited to within a few meters of the borehole walls. The modified-permeability zones around the boreholes are expected to be limited to within a distance of a few radii from the walls, as they are in the results for a shaft Case and Kelsall (1987). The change in permeability around the drillholes may be permanent. But because the repository is over 100 m below the deepest of these holes, the potential changes in permeability are not expected to affect the water flux at the repository horizon.

Shallow boreholes are not expected to become preferential pathways for fluid or gas flow because of their relatively shallow depth (60 m) and because they will be sealed. Therefore, this activity should not result in permanent effects on the site that would affect performance.

<u>Deep borings drilled dry</u>

The plans for deep borings using dry drilling include unsaturated-zone holes, which will include drilling to just above the water table, multi-purpose boreholes drilled to the depth of the nearby exploratory shafts, and

the systematic drilling program, which will include drilling to 100 m below the water table.

Potential impacts from hydrologic disturbances

The potential changes in the unsaturated zone for deep borings will be similar to the changes discussed for shallow borings earlier in this section. As discussed for shallow boring, the effects of drilling with air on the air pressure are dissipated relatively quickly and near-initial conditions are reestablished in about one day. According to the results of the analyses discussed in topic 5 of Section 8.4.3.2.1.4, there may be a small decrease of about 0.005 in the moisture content of the rock matrix from the movement of air into and out of the matrix during drilling. This small change in moisture content within a few centimeters of the wall of the drill hole is a transient condition and is not expected to significantly affect the net infiltration and the percolation flux at the repository horizon.

Potential impacts from geochemical disturbances

The evaluation of geochemical disturbances that could affect site performance by altering the environment near waste packages, reducing the capability of the tuff to retard transport of radionuclides, or affecting the flux of water at the repository horizon for deep dry-drilled boreholes is similar to the evaluation for shallow boreholes previously discussed.

Potential impacts from thermal/mechanical disturbances

The evaluation of thermal and mechanical disturbances that could affect site performance by altering the hydraulic conductivity of the rock mass or changing the environment near areas of waste emplacement is similar to the evaluation for shallow boreholes previously discussed. There may be small temporary increases in temperature that may change the moisture content of the rock matrix near the borehole wall, but this change should not impact postclosure performance.

The change in permeability around the drillholes caused by drilling will be a permanent effect. But since these boreholes will be located, to the extent practicable, in pillars in the proposed repository, they are expected to be approximately 30 m from the nearest waste package. Analyses discussed in Section 8.4.3.2.1.2 suggest that flux through such a modified permeability zone around the borehole will move only a short distance before being imbibed into the matrix. In any event, the boreholes will be sealed if necessary to mitigate any potential effects. Therefore, the permanent change in permeability around these boreholes is not expected to impact postclosure performance.

Deep boreholes are not expected to become permanent preferential pathways for fluid or gas flow because they will be sealed. Furthermore, in the underground facility they will be located in pillars, to the extent practicable.

Geologic coreholes drilled with water

Geologic coreholes using standard wireline coring methods have been drilled to depths of 1,500 m, using water with a polymer additive. No new geologic coreholes are currently planned within the conceptual perimeter drift boundary. But as discussed in Section 8.4.2.1.1, three proposed geologic coreholes are located outside the controlled area and outside the possible expansion area proposed in the Yucca mountain environmental assessment (DOE, 1986b). Three existing holes have been drilled with similar methods in which the principal circulation medium was water with polymer additives. (Bentonite mud and other materials were occasionally used for circulation.) The loss of fluid during the drilling of test well USW G-1 is discussed in Section 8.4.3.2.1.2. Since no additional coreholes are proposed within the proposed repository boundary, there should not be any effects on the hydrologic, geochemical, or thermal/mechanical conditions.

Saturated-zone boreholes

Eight additional saturated-zone boreholes are planned to explore and sample the water table in the vicinity of the site as part of the site characterization activities. Only one of these additional boreholes will be drilled within the conceptual perimeter drift boundary (CPDB). This borehole, identified as USW H-7, is planned to be drilled to below the water table using dry drilling methods at least through the unsaturated zone. Since borehole USW H-7 is the only saturated-zone borehole within the CPDB, the following discussion will focus on its impacts on site performance.

Potential impacts from hydrologic disturbances

The impacts to the site from hydrologic disturbances will be evaluated by considering the alteration of the amount and distribution of ground-water flux at the repository horizon and changes to the hydrologic characteristics of the unsaturated zone. The potential impacts to the unsaturated zone from the saturated-zone boreholes drilled dry will be nearly identical to the discussion for the shallow boreholes drilled dry. There may be a small decrease in the moisture content of the rock matrix from air moving into and out of the matrix during drilling, as discussed in topic 10 of Section 8.4.3.2.1.1. This change in moisture content near the wall of the borehole would be of short duration and is not expected to significantly affect the characteristics of the unsaturated zone or the ground-water flux at the repository horizon.

Potential impacts from geochemical disturbances

Potential impacts of geochemical disturbances to the unsaturated zone from dry drilling to the saturated zone will be similar to the potential impacts for drilling shallow boreholes. A small amount of oil may be introduced into the rock wall during dry drilling. As discussed in Section 8.4.2.1.2.6, the dry drilling method to be used will be tested and the effects of oil on rock matrix properties evaluated before this borehole is drilled. West (1988) estimated that fluid would only penetrate a few centimeters into the rock matrix and that no significant interactions of oil with other construction materials should occur.

The drilling method selected for the saturated zone is not expected to have a geochemical impact on the unsaturated zone. This change is a localized effect that should remain near the drillhole and not affect the environment near the waste package, reduce the capability of the tuff to retard transport of radionuclides, or significantly affect the water flux at the repository horizon.

Potential impacts from thermal/mechanical disturbances

The thermal/mechanical impacts on site performance by drilling a saturated-zone borehole should be similar to the evaluation of impacts for deep borings that drilled dry. There may be small, temporary increases in temperature that could change the moisture content of the rock matrix near the borehole wall, but they should not affect the hydraulic conductivity of the rock mass or the waste-package environment.

Mechanical disturbances to fracture apertures and the effects on the hydraulic conductivity due to dry drilling are expected to be limited to within a few meters of the borehole wall. Flux through the modified permeability zone around the borehole should move only a short distance before being imbibed into the matrix. Since this borehole will be backfilled and sealed, and there will be a relatively large lateral distance between it and waste emplacement areas, it is not expected to create a preferential pathway for liquid or gas flow.

### 8.4.3.2.5.3 Potential impacts to the site from construction of the exploratory shafts

The potential transient and permanent impacts from hydrologic, geochemical, and thermal/mechanical disturbances to the site from construction of the two exploratory shafts are evaluated in this section. The detailed summaries of the hydrologic, geochemical, and thermal/mechanical analyses and data discussed in Section 8.4.3.2 provide the basis for evaluating the potential impacts.

The shaft-sinking operation for both shafts will consist primarily of drilling small-diameter blast holes into the rock, loading the blast holes with explosives, and producing detonations. The detonations will be timed to control the blast, which will enhance vertical advance, limit damage to the rock zone, and produce acceptably-sized rock fragments. Following the blast, air will be exhausted to remove smoke, dust, and fumes. The rubble will be sprayed with water for additional dust control before muck is removed. After several blasting rounds, the shaft-liner concrete will typically be installed in 20-ft (6-m) segments. Water use during construction of the exploratory shafts will be controlled to limit potential impacts on the site, and all water used will be tagged with a tracer to distinguish it from natural ground water. The construction of the exploratory shafts is detailed in Section 8.4.2.3.4.

Potential impacts from hydrologic disturbances

Hydrologic disturbances from exploratory shaft construction could affect the site mainly by altering the amount and distribution of flux at the repository horizon and by changing the hydrologic properties of the unsaturated zone (primarily the hydraulic conductivity). The shafts will be approximately 12 ft in diameter, with a region of disturbed rock around the openings. As discussed in Section 8.4.2.3, water use will be controlled to limit potential impacts to the site. However, some of the water used to drill the blast holes and used to control dust will be retained in the walls surrounding the exploratory shafts. Current estimates are that approximately 10 percent of the water used during the drilling and blasting of the shafts will be retained in the walls (West, 1988). Analyses discussed in Section 8.4.3.2.1 indicate that water introduced to the rock formations from the shafts will change the saturation of the rock only slightly, and these changes will generally be limited to approximately 10 m from the opening.

Equilibration of the water is expected to occur within several months. Analyses presented in Section 8.4.3.2.1.3 predicted that the saturation change at the repository horizon would be less than about 0.002. The farther that the retained water moves from the shaft walls into the rock matrix, the smaller the overall change in saturation. The small change in saturation over the small volume of rock affected is a short-duration change and will not significantly change either the percolation flux at the repository horizon or the value of the unsaturated hydraulic conductivity (which is a function of the degree of saturation). Case and Kelsall (1987) analyzed the potential change to the rock hydraulic conductivity in the modified permeability zone caused by shaft construction and concluded that the change is small after approximately 2 to 3 m from the shaft opening.

West (1988) discusses other fluids besides water (such as antifreeze, hydraulic fluid, and diesel fuel) that will be used during the construction of the exploratory shafts. The quantities of these fluids remaining in the rock walls should be much lower than the volumes of water used for construction and the fluids should remain near the shaft walls. As discussed in Section 8.4.2.3.3, fluids recovered during construction operations will be disposed of to avoid the potential for performance impacts. Therefore, because of the construction controls to be used for the exploratory shaft, no permanent impacts on the site-performance from these fluids could be identified.

Potential impacts from geochemical disturbances

Changes in geochemistry could potentially affect site performance by altering the environment near waste package, reducing the capability of the tuff to retard transport of radionuclides, or changing the flux of water by altering flow paths. West (1988) discusses the type, quantity, and potential interactions of the fluids and materials that will be used during the construction of the exploratory shafts. The construction will introduce explosives, concrete, utility piping, instrument conduits, rock bolts, steel tendon rods, and tagged water. West (1988) did not identify any interactions between fluids and materials used during construction that would have a significant, permanent geochemical impact on the site. West (1988) also

evaluated the gaseous products produced from the explosives and the penetration distance using controlled blasting procedures. This evaluation suggested that small amounts of the gases, such as NO, CO, $NH_2$, and $CH_4$, and some solids, such as $Al_2O_3$, will be produced. Although most of the gaseous products will be ventilated to the surface, some of the gaseous products may penetrate 1 to 2 m into the rock.

Fernandez et al. (1988) analyzed the potential effects of the interaction of the shaft concrete liner with ground water. They concluded that some chemicals may form precipitates, but these would be localized and would not be transported far from the shaft wall.

Therefore, the construction of the exploratory shafts could cause some small, permanent geochemical changes to the rock near the shaft wall. But because of the distance between the shafts and areas of waste emplacement, these geochemical changes will not alter the environment near waste packages, nor will they reduce the capability of the tuff to retard transport of radionuclides.

Potential impacts from thermal/mechanical disturbances

Construction of the shafts will cause permanent changes to the rock mechanical conditions around the shaft openings. As discussed in Section 8.4.3.2.3, changes in these conditions resulting from stress redistribution and blast damage will alter the rock hydraulic conductivity in a modified permeability zone extending a few meters into the wall rock (Case and Kelsall, 1987). The disturbed rock mass conductivity is predicted to be increased by less than a factor of 2 to 3 at distances greater than approximately 5 m from the shaft wall. These changes to hydraulic conductivity were considered previously in this section in evaluating potential changes to percolation flux, hydrologic properties, and the potential to create preferential pathways. They were determined to not significantly affect postclosure performance.

Fernandez et al. (1988) have analyzed the potential for the exploratory shafts to become preferential pathways for liquid and gaseous transport. The exploratory shafts, which will be backfilled and sealed, are permanent features, as is the modified permeability zone (MPZ) around each shaft opening. The MPZ (Case and Kelsall, 1987) is the region approximately 2.2 m from the shaft wall, beyond which the permeability changes to the rock from construction are insignificant. Fernandez et al. (1988) analyzed a flooding scenario to predict the volume of water that could enter the ESF through fracture systems in the uppermost tuffaceous units due to a probable maximum flood. They also analyzed the potential for episodic water to percolate through the shaft fill and the MPZ and concluded that, for both analyses, the backfilled shafts and associated MPZs will not become liquid pathways such that the capability of the site to meet the postclosure performance objectives is affected. The potential for the shafts and MPZs to function as preferential pathways for gaseous transport was also analyzed. Fernandez et al. (1988) concluded that if the air conductivity of the shaft fill is less than about $3 \times 10^{-4}$ m/min, the exploratory shafts (including shaft fill and MPZ) are not likely to be preferential pathways. The potential impacts of the shafts on total system release is discussed in Section 8.4.3.3.1.

The liner is expected to be removed using existing technology from below the repository horizon and, thus, is not a permanent feature at those depths (Fernandez et al., 1988). Fernandez et al. (1988), identified six techniques for liner removal: hand-held pneumatic breakers, drill and blast, drill and use of a hydraulic splitter, drill and use of a nonexplosive demolition agent, impact breaker, and road header boom. Considering the advantages and disadvantages for each method, the drill and use of hydraulic splitter method is considered the favored approach for liner removal, although the other approaches are technically feasible.

According to these evaluations of potential impacts resulting from exploratory shaft construction, the permanent changes to the site are the creation of two shaft openings and a modified zone of permeability around the openings. These changes are not expected to significantly impact the hydrologic, geochemical, and thermal/mechanical conditions of the site. Changes to the site from introducing fluids and materials are expected to be transient.

#### 8.4.3.2.5.4 Potential impacts to the site from underground construction of exploratory shaft facility drifts and testing alcoves

The potential impacts to the site from underground construction of exploratory shaft facility drifts and testing alcoves are evaluated in this section. Hydrologic, geochemical, and thermal/mechanical analyses and data that provide the basis for evaluating the potential impacts resulting from these activities are summarized in previous sections. Section 8.4.2.3 discusses these construction activities, including construction of the upper demonstration breakout room at a depth of approximately 175 m and the main testing area at the depth of the proposed repository horizon. The underground drifts and testing alcoves will be mined by conventional drill, blast, and muck methods.

Potential impacts from hydrologic disturbances

Like the methods for construction of the exploratory shafts, underground construction methods use water, primarily for drill-and-blast activities and for dust control. The water use will be controlled (Section 8.4.2.3), and approximately 10 percent of the water used is currently estimated to be retained in the rock (West, 1988). The analyses discussed in Section 8.4.3.2.1 indicate that water introduced to the rock formations from underground construction will change the saturation of the rock only slightly. This change will generally be limited to approximately 10 m from the opening. The initial changes to saturation will be transient because equilibration is expected to occur within several months (see analyses in Section 8.4.3.2.1). The predicted saturation change at the repository horizon would be less than 0.002. As the distance the water might move from the shaft increases, the overall change to saturation decreases. The changes to saturation will generally be transient and will not significantly increase either the percolation flux at the repository horizon or the value of the unsaturated hydraulic conductivity. The fraction of volume excavated within the ESF is small and is also not expected to significantly alter the flow field, or percolation flux, around the excavated openings.

Additionally, the ventilation system will remove water from the exposed underground walls. As discussed in Section 8.4.3.2, the ventilation system may remove a volume of water comparable to the volume of water retained during construction. Therefore, the effects of ventilation may further reduce the transient effects to flux and hydraulic conductivity caused by introducing water to the rock formations.

Potential impacts from geochemical disturbances

The potential impacts of geochemical disturbances from underground construction of drifts and testing alcoves will be similar to those from the construction of the exploratory shafts. Changes in geochemistry could potentially affect the site, primarily by altering the environment near waste emplacement. West (1988) discusses the type, quantity, and potential interactions of the fluids and materials that will be used during the construction of the drifts and testing alcoves. As in the evaluations made concerning shaft construction, West (1988) did not identify any interactions between fluids and materials used during construction that would have a significant, permanent impact on the site. West (1988) considered geochemical disturbances from such items as explosives, concrete, utility piping, instrument conduits, rock bolts, steel rods, tagged water, hydrocarbons from machinery, and gases and also evaluated the gaseous products of the explosives and the penetration distance using controlled blasting procedures. This evaluation indicated that most of the gaseous products would be ventilated to the surface, with some of the gaseous products potentially penetrating 1 to 2 m into the rock.

Therefore, the construction of the underground drifts and testing alcoves will cause some small permanent changes to the rock near the excavated openings. Because of the distance between the openings and emplaced waste, however, these geochemical changes are not expected to significantly alter the environment near the waste emplacement.

Potential impacts from thermal/mechanical disturbances

The underground drifts and testing alcoves within the ESF will be permanent features, but are not expected to function as preferential pathways for either liquid or gaseous radionuclides. Neither the drifts nor the alcoves directly intersect the accessible environment. The drifts and alcoves are predominantly horizontal features that will be laterally separated from the emplaced waste by at least 30 m. The drifts and alcoves are designed to provide internal drainage for the ESF to the sump for ES-1. They will connect to the shafts; but as discussed in the previous section, the shafts are not expected to function as preferential pathways. Therefore, the drifts and alcoves are not expected to provide a preferential pathway for radionuclide transport to the biosphere.

The underground construction will be performed by drilling rounds of small-diameter shot holes into the rock face, loading them with explosives, and then blasting. As discussed in Section 8.4.3.2.3, changes in stress will occur around the openings, resulting in changes to the rock mass hydraulic conductivity. As with the construction of the exploratory shafts, the changes in conductivity around the drift are expected to be increased by less than a factor of 2 to 3 at distances greater than approximately 5 m from the

wall (Case and Kelsall, 1987). Hill (1985) predicted that changes to stress were effectively limited to about one drift diameter around a drift opening. St John (1987b) considered the use of rock bolts and concluded that the bolts have a negligible effect on drift stress and deformation. The permanent changes to hydrologic properties are, therefore, not expected to be significant at distances greater than approximately 5 m from the excavated opening.

According to these evaluations of potential impacts resulting from underground construction of drifts and testing alcoves, the permanent changes to the site are primarily the creation of drift openings and the zone of modified permeability around the openings. Changes to the site from introducing fluids and materials are expected to be generally transient and insignificant. The permanent changes are not expected to significantly impact the hydrologic, geochemical, and thermal/mechanical conditions of the site.

### 8.4.3.2.5.5 Potential impacts to the site from exploratory shaft facility activities

The potential transient and permanent impacts to the site from ESF hydrological, geochemical, and thermal/mechanical testing activities are evaluated in this section. The detailed summaries of the hydrologic, geochemical, and thermal/mechanical analyses and data discussed in Section 8.4.3.2 provide the basis for evaluating the potential impacts.

The testing activities in the ESF include the multipurpose borehole (MPBH) tests, construction-phase tests, and in situ tests. The proposed MPBH and construction-phase testing primarily consist of sampling materials and fluids that are encountered during construction and monitoring the effects of construction. Therefore, these two testing activities should not impact the site conditions, and they will not be discussed in this section. The in situ tests will introduce additional fluids into the unsaturated zone and may cause some thermal/mechanical changes. A detailed description of the ESF testing activities is presented in Section 8.4.2.3.1.

<u>Potential impacts from hydrologic disturbances</u>

Hydrologic disturbances from ESF testing activities could potentially impact site performance by increasing the water flux at the repository horizon or by changing the hydrologic properties of the unsaturated zone. Two tests have currently been identified to be performed in the ESF that may introduce water into the unsaturated zone. These tests are the infiltration tests and the cross borehole water injection test.

Because the test block for the infiltration test will be separated from the rock mass and isolated within the drift, the water added to the rock can be recovered. Section 8.4.2.3.1 identifies a cross borehole water injection test as part of the test to evaluate hydrologic properties of major faults encountered at the main test level of the ESF test. Because this test is still in the early planning and development stage, the volume of water to be injected into the fault region has not yet been determined. The volume of

water to be injected will, however, be carefully controlled. The potential impacts of the water to be injected will be assessed before testing. Therefore, the currently identified tests will not introduce a significant amount of water to the unsaturated zone, and the water used in these tests will not result in permanent changes.

Potential impacts from geochemical disturbances

Geochemical disturbances during ESF could affect site performance by altering the environment near areas of waste emplacement, reducing the capability of the tuff to retard transport of radionuclides, or affecting the flux of water at the repository horizon. The only test with a potential for chemical disturbances is the diffusion test, which will use a nonsorbing tracer. In Section 8.4.3.2.1, the tracers are estimated to move about 0.1 m into the rock around the test hole. Therefore, the potential geochemical impact from chemicals introduced during testing should be a very local effect near the test.

In summary, the permanent geochemical changes to the site from ESF testing are expected to be small and contained near the testing area. These changes should not affect the environment near waste package emplacement, the capability of the tuff to retard transport of radionuclide, or the groundwater flux at the repository horizon.

Potential impacts from thermal/mechanical disturbances

Thermal/mechanical disturbances could affect site performance by altering the hydraulic conductivity of the rock mass, by causing geochemical changes in the environment near waste packages or by creating preferential pathways for flow. The testing activities include several tests that involve mechanical effects and thermal/mechanical effects. The zone of influence estimated for these tests discussed in Section 8.4.2.3.1 indicates that the disturbances will be constrained to near the testing locations.

Tests that introduce heat into the rocks will be performed in the ESF that may change the moisture distributions around the heaters. The moisture may vaporize and move from the heated regions to the cooler regions where it will be condensed. Section 8.4.2.3.1 identifies the zones of influence for the various heated tests. The maximum zone of thermal influence was about 20 m from the heated room test. Because the heated region for the heated room test is bounded by two access drifts that are ventilated, the region of potential hydrologic alteration is not likely to extend beyond the access drifts. Other than the heated room tests, the maximum zone of thermal influence was about 14 m. The change in matrix moisture content will be relatively local during testing, and at the termination of the testing, the moisture will move back into the rock dried out by the heaters. (These tests will be specifically located at standoff distances large enough to avoid test-to-test interference.) Therefore, the currently identified tests should not have thermal effects that would cause areas of increased flux in the repository horizon or changes to the hydrologic properties of the unsaturated zone that would adversely affect postclosure performance. The ESF tests are not expected to provide preferential pathways for the movement of fluids to the accessible environment.

The tests that introduce heat may cause geochemical changes in the rock from the increase in temperature and from the chemicals remaining in the rock after vaporization of in situ water. As noted earlier, however, the area influenced by thermal effects is a relatively local area near the tests.

### 8.4.3.3 Potential impacts of site characterization activities on postclosure performance

The impacts of disturbances from site characterization activities on the postclosure performance objectives for total system releases, waste-package containment, EBS release rates, and ground-water travel time are discussed in this section. The issue resolution strategy for each performance objective is briefly summarized. These strategies identify the system elements and the performance measures relied upon to achieve and demonstrate that the performance objectives have been met. The potential impacts of each of the five categories of site characterization activities on the performance measures of the system elements are discussed. Because of the comprehensive scope of the performance objective for total system release, the discussion provided for this objective is more extensive than the discussions for the other three performance objectives.

The evaluations of the potential impacts of site characterization activities on postclosure performance are based on the current conceptual model of unsaturated flow discussed in Section 8.4.1.3. Section 8.4.3.1.1 describes the general approach to performance assessment used in this section and indicates that the interpretation of current data is based primarily on physical concepts of unsaturated flow in a porous, fractured rock such as the rock at the potential repository horizon at the Yucca Mountain site. The interpretations of the data will be continuously reevaluated during site characterization as alternative models for unsaturated flow at Yucca Mountain are refined (Section 8.3.1.2.2).

#### 8.4.3.3.1 Impacts on total system releases

##### 8.4.3.3.1.1 Summary of issue resolution strategy

The performance objective for releases of radioactivity from the total system is described in Section 8.3.5.13 (Issue 1.1). In accordance with Section 60.112 of 10 CFR Part 60 and in Section 191.13 of 40 CFR Part 191, the performance measure for the total system is the complementary cumulative distribution function (CCDF) for the normalized, cumulative release of radioactivity to the accessible environment for 10,000 years following permanent closure, owing to the action of all significant events and processes that may affect the geologic repository. As described in Section 8.3.5.13, the CCDF will be numerically constructed by Monte Carlo simulation with a total system simulator, which is composed of mathematical models of the action of significant events, processes, and features on the amount of radioactivity released to the accessible environment in the period of performance. The significant events and processes to be incorporated in these mathematical

models--as well as some of the physical principles to be embodied in the models--are to be determined from the information developed during site characterization.

A preliminary identification of potentially significant events, processes, and features is made in Section 8.3.5.13 in order to guide the collection of this information. The requirements in 40 CFR 191 depend on the likelihood of the significant events and processes; thus, Section 8.3.5.13 divides these processes and events into scenario classes. The nominal scenario class contains those events and processes that are reasonably likely to occur in the 10,000-yr period following permanent closure. The disruptive scenario class contains processes and events that are credible enough to warrant consideration but whose likelihoods lie outside the range of those in the nominal class. Section 8.4.3.3.1.2 uses the scenario classes for the evaluation of impacts on total system releases. A more complete discussion of the processes and events, the nominal and disruptive scenario classes, and an explanation of how those scenario classes were selected are given in Section 8.3.5.13. The use of the scenario classes as tools for the analyses and derivations in Section 8.3.5.13 and in this section does not imply that the events and processes are likely to occur. The likelihoods and consequences of most of the scenarios can be established only after site characterization has provided the necessary information.

According to Table 8.3.5.13-8, which lists the preliminary performance allocation for this performance objective, the components to be relied on for meeting the objective vary with the release scenario class. The unsaturated zone, however, will be the primary component to be relied on to mitigate deleterious effects of many of the events, processes, and features that will be considered. For some events, processes, or features, the saturated zone or engineered systems will also be relied on.

#### 8.4.3.3.1.2 Evaluation of impacts on total system releases

This section evaluates whether site characterization activities can be expected to preclude the capability of the site to meet the postclosure performance objective governing the total-system release of radioactivity over the 10,000-yr period following permanent closure (as required by 40 CFR 191.13). These evaluations are based on estimations of the effects of the site characterization activities on current site hydrologic, geochemical, and thermal/mechanical conditions. Section 8.4.3.2 presents the analyses that underlie the estimations, which are summarized in Section 8.4.3.2.5. Some of these effects are transient, becoming insignificant before closure or early in the 10,000-yr isolation period; others are more permanent, persisting well into the isolation period. The estimates of both kinds of effects are used here to evaluate potential effects on current site performance. The more permanent effects are the basis for evaluating whether site characterization activities will, under future conditions, be likely to make the site unable to meet the total system release requirements.

The evaluations of impacts are also based on an understanding of the characteristics of the unsaturated zone (Sections 3.9 and 8.4.1.3), the types of site characterization activities currently planned (Section 8.4.2), and

the design features that avoid or mitigate the potential impacts (Sectios 8.3.3.1 and 8.4.1.2). Section 8.4.2.1 identifies five types of site characterization activities: surface-related activities, drilling activities, exploratory-shaft construction, underground construction of drifts and alcoves, and testing activities in the exploratory shaft facility.

For convenience in making these evaluations, this section is organized according to the nominal and disruptive scenario classes developed in Section 8.3.5.13 and briefly summarized in Section 8.4.3.3.1.1. This organization helps to ensure that all the events and processes currently considered worthy of further investigation are examined. The discussion of events and processes in the nominal scenario class is in two parts. The first deals with the events and processes that currently exist at the Yucca Mountain site; these phenomena are summarized in Section 8.4.1.1.3. The evaluation of the effects of site characterization activities on these phenomena examines both the transient and the more permanent effects of the activities.

The second part deals with the processes and events that, though not believed to exist now at the site, the DOE considers worthy of investigation as potentially likely phenomena. These are phenomena that, if proved to be likely during site characterization, will be part of the nominal scenario class used in constructing the CCDF. The 16 processes and events in this category are as follows:

1. Climatic change.
2. Flooding.
3. Geochemical changes.
4. Undetected faults and shear zones.
5. Undetected dikes.
6. Faulty waste emplacement.
7. Undiscovered boreholes.
8. Undiscovered mine shafts.
9. Differential elastic response to heating.
10. Inelastic response to heating.
11. Thermally driven water migration.
12. Local mechanical fracturing.
13. Corrosion.
14. Chemical reaction of waste package with rock.
15. Geochemical alteration.
16. Microbial activity.

Presence on the list does not indicate that the DOE currently believes a process or event is likely. Some of them (e.g., undiscovered mine shafts) are in the list only to request site characterization information that will allow a definitive decision as to whether they can be eliminated from further consideration.

After the two discussions of events and processes in the nominal scenario class, this section investigates how the more permanent effects of site characterization activities would affect site behavior if unlikely disruptive events occur in the future. Initiating events and processes in the disruptive scenario class in the following list are examined in this section.

1. Extreme climate change.
2. Stream erosion.
3. Faulting and seismicity.
4. Magmatic intrusion.
5. Extrusive magmatic activity.
6. Irrigation.
7. Intentional ground-water withdrawal.
8. Exploratory drilling.
9. Resource mining.
10. Climate control.
11. Surface flooding or impoundments.
12. Regional changes in tectonic regime.
13. Folding, uplift, and subsidence.

Again, not all the items in the list are currently considered likely enough to be included in the complementary cumulative distribution function. This list has been developed as a guide for site characterization, and the DOE expects that site characterization will show many of the events or processes to be insignificant because their consequences or their likelihoods are small.

The evaluations pay much attention to the unsaturated zone because it is the primary barrier relied upon to isolate the emplaced wastes from the accessible environment over the 10,000-yr period of performance. Major features in the current conceptual models of the unsaturated zone that are important to these evaluations include the dampening of surface infiltration events at depth in the unsaturated zone; low ground-water flux at depth; ground-water flow mainly through a fractured, porous matrix, with water in the fractures drawn by capillarity into the partially saturated porous matrix; movement of water in fractures when the porous matrix is at or near saturation; and possible perching of ground water in areas of distinct permeability contrast such as a porous, nonwelded tuff overlying a fractured, welded tuff. The evaluations pay less attention to the saturated zone because it is a secondary barrier, few site characterization activities are planned in the saturated zone, and potential impacts of these site characterization activities on waste isolation are expected to be minor.

Because compliance with total system performance objective relies on the hydrologic properties of and conditions within the unsaturated zone between the repository and the water table, all three of the following discussions focus on changes to these properties and conditions as a result of site characterization activities. A significant decrease in the ability of the unsaturated zone to chemically or physically retard the transport of radionuclides would also adversely affect the ability of the site to meet the total system performance objective. The possible adverse effects on the hydrologic properties and conditions in the unsaturated zone fall into three primary classes: (1) significant changes to the amount or spatial distribution of ground-water flux; (2) significant changes to the hydrologic properties, principally hydraulic conductivity; and (3) the creation of pathways for rapid flow of liquids.

Analysis results important to the evaluations of effects

Drawing from the more detailed discussions in Section 8.4.3.2, the next several paragraphs briefly discuss some results of analyses of the effects of site characterization. The expectations based on these results are important in many of the evaluations presented in the three discussions according to scenario classes; they are accordingly reviewed here before the three discussions.

Since they will not be present during site characterization, engineered components will not be directly affected by site characterization activities, but they might be indirectly affected in the future because of changes in site hydrological, geochemical, or thermal/mechanical conditions. The activities are also not expected to significantly affect the performance of the saturated zone because the little testing that will be performed within the saturated zone by drillholes will not significantly change the hydrologic or geochemical conditions around the boreholes. Gas-phase releases from the repository may not be significantly affected if site characterization activities do not create preferential pathways for gas flow. The performance allocation in Section 8.3.5.13, however, places primary reliance upon the waste form, not the geologic barriers, to ensure system performance in the presence of gas-phase releases. Additional study during site characterization will better define the roles that natural barriers and engineered barriers, such as seals, can be expected to play in limiting potential gas-phase releases. For example, the backfilled and sealed shafts and boreholes from site characterization would not constitute gas-flow pathways if the backfill material had an air conductivity of less than $3 \times 10^{-4}$ m/min.

Evaluations of water artificially introduced to the site during site characterization have been made in Section 8.4.3.2; those evaluations indicate that water will generally move only a relatively short distance (approximately 10 m or less) from a penetration under small heads and that the final change in saturation of the disturbed volume around the penetration will be extremely small (a few percent or less). Compared with the period of performance (10,000 years), the time required for water introduced by site characterization activities to reach near-equilibrium conditions is extremely short (estimated to be days to months depending on local rock hydrologic properties; Section 8.4.3.2.1). These small and localized changes in saturation around penetrations are not expected to significantly affect the amount or spatial distribution of ground-water flux or the hydraulic conductivity. They are also not expected to affect the release of radioactivity to the accessible environment for either the nominal or the disruptive scenario classes. Furthermore, the initial perturbations due to site characterization activities are short compared with the period of performance and generally will be laterally well separated from emplaced waste.

Analyses in Section 8.4.3.2 indicate that changes in stress and rock mass permeability will be small outside of two opening-diameters (less than 9 m for the exploratory shafts) away from the penetration.

The evaluations of artificially introduced chemicals to the site are made in Section 8.4.3.2. Those evaluations indicate that the distance of geochemical effects around a penetration is constrained by the distance water

moves and will be limited to approximately 10 m or less. In addition, the more volatile chemicals will tend to evaporate over time and to diffuse and become diluted within the partially saturated rock matrix. The retardation capability of the rock will not generally be altered outside of this distance.

The evaluations made in Section 8.4.3.2 thus indicate that many of the possible changes to site hydrologic, mechanical, and geochemical conditions are generally limited to distances within approximately 10 m of a penetration and are often short-lived. Because the site characterization activities will be separated from waste-emplacement areas by more than 10 m, and because this objective considers the cumulative release of radioactivity from the entire repository, the localized and limited changes to site hydrologic, geochemical, and mechanical conditions are judged not to be significant. (Further discussion is presented in the evaluations of events and processes in the nominal scenario class where present site conditions are considered.) The focus of the evaluations of potential impacts to this performance objective (if the events or processes listed for the nominal and the disruptive scenario classes should occur) will be whether the penetrations from site characterization could create preferential pathways.

Considerable attention has been given in planning and selecting construction activities to avoid or limit potential impacts (e.g., by selecting dry-drilling methods for boreholes within the repository block, controlling water use during drill-and-blast activities, controlling drill-and-blast activities, and avoiding blockage of natural surface-water drainageways). Most impacts that do occur are expected either (1) to be of short duration or reversible (e.g., the effects of watering for dust control at the ground surface and water introduced during drill-and-blast activities that is quickly removed with the muck or by the ventilation system) or (2) to be spatially limited (e.g., increased infiltration due to ground disturbance and the creation of a modified permeability zone (MPZ) around boreholes, shafts, and drifts).

Impacts that are of primary concern for these evaluations are those that may be pervasive in time and space. Examples of such effects are those that would persist during the period of performance and result in (1) significantly increased flux at the repository depth (e.g., the potential effects of surface-water impoundments); (2) significantly changed hydraulic properties or hydrochemistry (e.g., the potential effects of drill-and-blast activities); and (3) the creation of preferential pathways (e.g., the potential effects of boreholes and shafts). As discussed in Section 8.4.3.2.4, some of the design features that are relied upon to ensure the performance of the natural barriers by limiting the potential impacts of site characterization activities include lateral separation of the waste-emplacement areas from the shafts, underground testing facility, and boreholes; drainage within the ESF away from waste emplacement areas to the sump in ES-1; and the sealing of boreholes, shafts, and drifts as described in detail in Section 8.3.3.1.

In addition to ensuring the performance of the natural barriers in meeting the total-system-release performance objective (10 CFR 60.112), the planning and selection of construction activities mentioned previously and the inclusion of design features mentioned in the previous paragraph demonstrate the incorporation of other provisions in 10 CFR Part 60 that

relate to waste isolation within the geologic repository program (e.g., portions of 60.133, "Additional design criteria for the underground facility," and 60.134, "Design of seals for shafts and boreholes").

Nominal scenario class: present site conditions

The potential impacts of site characterization activities on the performance of the site, with respect to present site conditions, have been evaluated for the five types of site characterization penetrations. These five types are briefly summarized here.

Surface-related site characterization activities are not expected to significantly alter the hydrology of the unsaturated zone below a few tens of meters. The potential effects of the planned surface-related activities have been estimated in Section 8.4.3.2.5 as an increase in surface infiltration into the alluvium (e.g., from trenching and ponding studies) or directly into the tuffaceous bedrock (e.g., from pavement studies). These effects, however, are of short duration and are damped out within the uppermost tuffaceous units as moisture is redistributed within the partially saturated matrix or is drawn from fractures into the partially saturated matrix.

For drilling activities, about 30 boreholes are currently expected to penetrate from the surface to the repository horizon or deeper within the conceptual perimeter drift boundary for the repository (Section 8.4.2.2). These boreholes will be sealed as described in Section 8.3.3.1 in order to restrict the movement of gaseous or liquid-phase fluids preferentially into or through the penetrations. In addition, the boreholes will be designed to be isolated, to the extent practical, in pillars laterally separated from waste-emplacement areas. The potential geochemical and mechanical changes that boreholes might induce are expected to be limited and confined well within these pillars.

The construction of the exploratory shaft, like the surface-related activities, will produce some small, short-duration increases in the saturation of the surrounding rock. These transient, localized effects will not significantly affect the flux or hydraulic properties of the unsaturated zone (Section 8.4.3.2.5.3). The more permanent effects of exploratory-shaft construction (potential geochemical changes and changes in stress conditions) are of limited spatial extent and are not expected to create preferential pathways. The shafts will be more than 30 m away from the emplaced waste. The shafts will not create preferential pathways because they will be sealed as described in Section 8.3.3.1 to restrict movement of gaseous or liquid-phase fluids preferentially into or through the penetrations. Fernandez et al. (1988) have calculated inflow from saturated near-surface fractures into a backfilled shaft (as described in Section 8.4.3.2.5) and have concluded that the quantity of water inflow will be small and the backfilled shaft will drain as rapidly as water enters. These analyses are also thought to be representative of flow from either saturated fractures or perched-water zones at greater depth. In addition, the analyses are thought to bound, by extrapolation, concerns about inflow into sealed boreholes.

A decision on the depth of penetration for the exploratory shaft ES-1 has been deferred until further evaluations are completed, study plans are prepared, and technical discussions are held with the NRC (Section 8.4.2.2).

These evaluations will cover such topics as the need to extend an exploratory shaft and drifting in the Calico Hills unit and the potential impacts of such penetration on waste isolation.

For the activities on underground construction of drifts and testing alcoves and testing activities in the exploratory shaft facility (ESF), the effects on the hydrology of the unsaturated zone, with the exception of the penetration created by excavation, are expected to be of short duration and laterally limited to within approximately 10 meters of the ESF (Section 8.3.2.5). The drifts and alcoves will be sealed as described in Section 8.3.3 in order to restrict movement of gaseous or liquid-phase fluids preferentially into or through penetrations. In addition, the ESF is laterally separated from waste-emplacement areas by at least 30 m, and the ESF will drain water internally to the sump of ES-1 to prevent movement of water from the ESF facility during operations or the waste emplacement areas during the postclosure period.

In summary, five types of site characterization activities have been evaluated for the present site conditions, and the performance of the site characterization activities as planned is not expected to preclude the capability of the site to meet the postclosure performance objective for total-system release of radionuclides to the accessible environment over the 10,000-year period following repository closure.

Nominal scenario class: potentially likely, but not currently present, conditions

The next paragraphs address the impacts of site characterization activities under those conditions that could be produced by events and processes that (after site characterization has produced the necessary information) may be considered likely to occur in the 10,000-year period following permanent closure. These conditions are listed earlier. For brevity, the evaluations generally assume a familiarity with the brief review of analysis results just presented and with Section 8.4.3.2.5. Plans for sealing are reviewed in Section 8.3.3.

The list of processes and events discussed in this section was developed for guiding site characterization. The DOE expects that site characterization information will show that at least some of them (and probably most of them) are unlikely or ineffective at the Yucca Mountain site. In this section, the list is used simply to ensure that the possible effects of site characterization activities are evaluated against the events and processes currently being considered for inclusion in the nominal scenario class.

This section briefly describes the 16 potentially likely processes and events, and identifies potential pervasive changes in site conditions that may be reasonably expected given the occurrence of the process or event. The section then focuses on the potential effects that site characterization activities might exert on compliance with the total system release performance objective under the conditions that would result if the process or event were to occur. Finally, this section addresses whether the planned site characterization activities can be reasonably expected to significantly affect the frequencies of occurrence or the magnitudes of the processes and events.

In most of these evaluations, the principal consideration is whether the process or event will result in an increased volume of water entering potentially preferential pathways created by the site characterization penetrations (e.g., boreholes, shafts, and drifts), either above the repository horizon (potentially resulting in a localized increase in flux across the repository horizon) or at or below the repository horizon (potentially resulting in gaseous-phase releases or localized drainage through a portion or all of the primary barrier for waste isolation). Other potentially adverse effects considered in the evaluations include significant changes in hydrochemistry (e.g., changes in the waste package environment or decreases in the ability of the unsaturated tuff to chemically or physically retard the transport of radionuclides released during the period of performance).

Note that this section is not intended to evaluate the potential effects of the processes and events on the total-system-release performance objective. Preliminary analyses of such effects were in the environmental assessment; final analyses, possible only after site characterization, will be in the license application.

Climate change

Climate change consists of a global warming due to increased atmospheric carbon dioxide, accompanied by an increase in summer precipitation of probably less than 50 percent. Subsequently, the onset of a cooler and wetter pluvial period is expected. Thus, climate change could increase flux, which could reasonably be expected to increase the volume of water moving from saturated fractures or perched-water zones into the site characterization penetrations.

Flooding

The flooding scenario consists of rapid runoff during severe summer thunderstorms in the washes draining Yucca Mountain, resulting in increased flux either through the alluvium into the tuffaceous bedrock or by interception of the runoff in open fractures in surficial bedrock. As in the climate-change scenario, the increased flux from the flooding could reasonably be expected to increase the volume of water moving from saturated fractures or perched-water zones into the site characterization penetrations.

Geochemical changes

The geochemical changes consist of the potential precipitation, solution, or alteration of minerals in fractures under current percolation flux that could significantly alter the internal fracture geometry, and consequently, the hydrologic properties of the fractures (e.g., blockage of small aperture fractures and diversion of flow into larger fractures). As in the previous scenarios on climate change and flooding, this scenario may be reasonably expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Undetected faults and shear zones

In scenarios that hypothesize the presence of undetected faults and shear zones that might affect the impacts of site characterization activities

on postclosure performance, the sequences to be considered include undetected wet zones associated with minor faults above the repository horizon and undetected major faults below the repository horizon through which enhanced moisture flow occurs. As in the previous scenarios, these sequences may be reasonably expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Undetected dikes

An undetected dike may provide a feature of very low matrix permeability, but high fracture permeability, thereby providing a pathway for increased volume of water that may be intersected by site characterization penetrations. As in the previous scenarios, the undetected dike may be reasonably expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Faulty waste emplacement

The scenarios that begin with faulty waste emplacement include several sequences, such as placing canisters in wet zones, improperly constructing drains around waste canisters, leaving canisters on the floor of the drifts or placing them too close together, improperly manufacturing canisters, or puncturing or abrading canisters during emplacement. These sequences may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Undiscovered boreholes

The undiscovered-borehole scenario begins with a horizontally emplaced waste canister lying in the trace of an old, undiscovered borehole. In addition, moisture conditions are wetter than currently existing conditions. This scenario introduces water directly to the repository horizon, which could result in an increased source term available for release through preferential pathways, if any, created by site characterization penetrations.

Undiscovered mineshafts

The undiscovered-mineshaft scenario consists of an old prospect in the bed of a wash that has filled with rubble and retains water after floods. This area allows a localized increase in infiltration that in turn results in a wet zone in which waste is emplaced. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations. Or, in the sequence where a borehole or shaft intersects the wet zone above the repository, the scenario may result in an increased volume of water moving from the wet zone into the site characterization penetration.

Differential elastic response to heating

The scenarios beginning with differential elastic responses to heating consist of several sequences, including diversion of flux into larger fractures in response to closure of small fractures as the result of thermal expansion, creation of open fractures in response to rock movements as the result of thermal expansion, and failure of waste canister in response to

stress corrosion or shearing as the result of thermal expansion. The first two sequences could result in localized increases in flux that could reasonably be expected to increase the volume of water moving from saturated fractures or perched-water zones into the site characterization penetrations. The last two sequences could result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Inelastic response to heating

The scenario beginning with inelastic response to heating consists of thermally induced fracturing of rocks immediately surrounding the waste canisters, which creates capillary breaks to the movement of moisture between blocks of the rock matrix. For these blocks, the matrix is saturated and water contacts the waste package. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Temperature-driven fluid migration

For the scenarios beginning with temperature-driven fluid migration, a two-phase convection system is created, and a saturated zone develops in an area of condensed moisture driven off as vapor by the thermal pulse. When gravity-driven flow again dominates the unsaturated zone, a large volume of water flows through the repository horizon. As a variation, temperature inhomogeneities may lead to localized accumulation of moisture above the repository, creating wet zones that bring water into contact with the wastes. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Local mechanical fracturing

For the scenario beginning with local mechanical fracturing, rock bursts are assumed to occur and propel rocks into waste packages, penetrating the canisters. This scenario may result in an increased source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Corrosion

The corrosion scenarios consist of several sequences that lead to failure of the waste canisters, including one sequence in which colloids of corrosion products sorb radionuclides that are normally highly retarded radionuclides and carry them away unretarded by chemical reactions with the rock. As in the previous scenario, this scenario may result in an increased (or, in this case, more mobile) source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Chemical reaction of waste packages with rock

The scenarios that begin with chemical reaction of waste packages with rock include several sequences wherein the dissolution rate of uranium is

above that predicted by the equilibrium solubility of uranium and wherein colloids transport radioelements with little or no retardation. As in the previous scenario, this scenario may result in an increased and more mobile source term available for release through preferential pathways, if any, created by the site characterization penetrations.

Chemical alteration

The chemical alteration scenarios consist of multiple sequences wherein the heating of the rocks around the repository results in mineralogy changes that clog pores and divert flow into fractures. Diversion of flow into fractures could reasonably be expected to increase the volume of water moving from saturated fractures into the site characterization penetrations.

Microbial activity

The microbial activity scenario consists of microbial activity that accelerates canister or cladding corrosion and sorbs radionuclides so that they move at the velocity of ground water, unaffected by sorption or matrix diffusion. This scenario may result in an increased and more mobile source term available for release through preferential pathways, if any, created by the site characterization penetrations.

As indicated previously, the principal consideration in this section is whether, given the occurrence of a process or event, site conditions will be changed such that the site characterization activities will adversely affect the capability of the site to meet the total systems release performance objective. In some scenarios (i.e., climate change, flooding, geochemical changes, undetected faults and shear zones, undetected dikes, undiscovered mine shafts, differential elastic response to heating, temperature-driven fluid migration, and chemical alteration), one of two major potential impacts is expected. Either the flux through the unsaturated zone would increase such that saturated flow conditions would exist in fractures or perched-water zones above the repository, or the site characterization penetrations would function as localized preferential pathways for gaseous or liquid-phase releases from the repository horizon. To the extent that site characterization activities within the conceptual perimeter drift boundary penetrated the Calico Hills formation, these penetrations could locally reduce the effectiveness of the primary barrier for waste isolation if the ground-water flux were to increase substantially in the formation. In several other scenarios (i.e., faulty waste emplacement, undiscovered boreholes, undiscovered mineshafts, differential elastic response to heating, inelastic response to heating, local mechanical fracturing, temperature-driven fluid movement, corrosion, chemical reaction of waste package with rock, and microbial activity), two other major potential impacts are expected. Either the hydrochemistry of ground water contacting the waste package changes or the radionuclide source term available for gaseous or liquid-phase transport through preferential pathways created by the site characterization penetrations increases. In the final three scenarios (i.e., chemical alteration, chemical reaction of waste package with rock, and microbial activity), the potential impacts included changes in the sorption capability of the tuffaceous rock.

As in the expectations for effects under present site conditions, the lateral separation of the site characterization penetrations from the waste emplacement areas, the drainage of the ESF internally to the sump for ES-1, and the sealing of the site characterization penetrations should ensure that these penetrations are neither preferential drainage points nor preferential pathways for gaseous or liquid-phase releases (Section 8.3.3.1). If there is a need to penetrate the Calico Hills formation with a shaft and drifts, further analysis will be needed to determine the potential impacts of these currently deferred site characterization activities on the primary barrier for waste isolation.

Site characterization activities are not expected to significantly change the hydrochemistry of the ground water over a significant time or distance or to significantly change the sorption capability of the tuffaceous rock (Section 8.4.3.2.5).

In summary, the performance of the site characterization activities as planned is not expected to adversely affect the capability of the site to meet the postclosure performance objective for total systems releases of radionuclides to the accessible environment over the 10,000-year period of performance. Site characterization activities are also not reasonably expected to significantly affect either the frequencies of occurrence or the magnitudes of the processes and events that may be considered (in the absence of further site characterization and analysis) likely to occur within the 10,000-year period of performance. Causal relationships were considered between the site characterization activities and the processes and events (e.g., reservoir-induced seismicity in the case of a large surface-water impoundment in the vicinity of an active fault zone). With the possible exception of postulated flooding in the vicinity of the exploratory shafts (which has been analyzed by Fernandez et al. (1988) as not adversely impacting the performance of the site), there do not appear to be any causal relationships whereby the planned site characterization activities are reasonably expected to significantly affect either the frequency of occurrence or the magnitude of the processes and events that may be considered likely to occur within the 10,000-year period of performance.

<u>Disruptive scenario classes</u>

This section describes the effects that low-probability, disruptive scenarios may have on present site conditions (e.g., hydrologic, geochemical, and thermal/mechanical conditions) in order to evaluate whether the site characterization activities (primarily boreholes and shafts) will adversely impact the postclosure performance objective under the conditions of the disruptive scenarios. The previous section described whether the site characterization activities would adversely impact compliance with the postclosure performance objective under anticipated conditions.

This section is not intended to dismiss any of the disruptive scenarios. That will require the evaluation of data collected in the site characterization program. Note that this section is also not intended to evaluate the potential effects of the disruptive scenarios on the total-system-release performance objective except in a general way. Preliminary analyses of such effects were presented in the environmental assessments (DOE, 1986b); final

analyses, possible only after site characterization, will be in the license application.

This section briefly describes the 11 disruptive scenario classes, and identifies potential pervasive changes in site conditions that may be reasonably expected if a scenario occurs. The section then focuses on the potential impacts of site characterization activities on the total systems release performance objective under the conditions that would result if the disruptive scenario were to occur.

For most of the evaluations, the principal consideration is an increased volume of water entering potentially preferential pathways created by site characterization penetrations (e.g., boreholes, shafts, and drifts) either above the repository horizon (potentially resulting in a localized increase in flux across the repository horizon) or at or below the repository horizon (potentially resulting in gaseous-phase releases or localized drainage through a portion or all of the primary barrier for waste isolation). Other potentially adverse effects considered in the evaluations include any significant change in hydrochemistry (e.g., changes in the waste package environment or decreases in the ability of the unsaturated tuff to chemically or physically retard the transport of radionuclides released during the period of performance).

The evaluations generally assume familiarity with the brief review of analysis results given earlier in this section and with Section 8.4.3.2.5.

Extreme climate change

As discussed in Section 8.3.5.13, extreme climate changes (i.e., changes that are not expected to happen during the next 10,000 yr) could potentially result in scenarios that increase the net infiltration into the unsaturated zone. As a further consequence, this increase could (1) increase the ground-water flux through the repository, (2) raise the water table because of the increase in recharge, (3) raise the water table and change the flow pattern, (4) raise the water table and create closer discharge points, (5) perch water above the repository and divert water into localized zones, and (6) perch water below the repository and divert water into fracture zones. Given the occurrence of any of these six sequences, the principal way site characterization activities could potentially affect performance would be by creating preferential pathways for liquid water movement. The summaries of effects on site conditions from performing characterization activities (Section 8.4.3.2.5) indicate that changes to the hydrologic conditions of the site will be small and localized near the penetrations.

Under the scenario of extreme climate change, the penetrations from site characterization activities are not expected to become preferential pathways because, as described previously, these penetrations will be backfilled and sealed. Furthermore, they will be laterally separated from the waste-emplacement areas and therefore distant from sources of radionuclides that the increased ground-water flux might transport. Under this scenario, local perched-water zones of saturated rock-matrix may develop, and ground water could flow into and through fractures intersecting a site characterization penetration. For the reasons just given, however, flow into the penetration--especially flow bearing dissolved radionuclides--would be expected to

be very small. Overflow of a large penetration is also not expected according to the evaluations summarized in Section 8.4.3.2. For example, Fernandez et al. (1988) analyzed inflow through fractures to the backfilled shaft and showed that water would drain out the bottom of the shaft as fast as it reached the bottom. Therefore, the DOE judges that, given the occurrence of extreme climate change, performing site characterization activities described in this document will not preclude meeting the total system release performance objective.

Stream erosion

No permanent streams occur within the repository drift boundary. Some ephemeral streamflow occurs at the site following intense precipitation events. The only sequence described in Section 8.3.5.13 related to the unsaturated zone is the erosion of the Tiva Canyon welded unit to expose the underlying nonwelded unit. The washes would then form barriers to lateral flow in the Tiva Canyon and divert flow downward, toward the repository. In addition, the NRC has raised the possibility of another sequence: lateral erosion in Coyote Wash such that the streamflow could be diverted into the backfilled exploratory shafts. In the first sequence, the penetrations from characterization activities would not generally be expected to act as pathways for water from the surface unless saturated fractures or perched zones are intersected by the penetrations. For this occurrence, the presence of a penetration would influence the water flow in a manner similar to the presence of a fault discussed in the next evaluation. In a study applicable to the second sequence, Fernandez et al. (1988) has analyzed inflow into a backfilled shaft and has shown that the shaft will drain quickly enough at the bottom to keep from filling to the repository level with water. Potential releases of radioactivity from the total system, given the occurrence of this scenario, thus would not be significantly changed because characterization activities were performed. Therefore, the DOE judges that, given the occurrence of the stream-erosion scenarios, performing site characterization activities described in this document will not preclude meeting the total system release performance objective.

Faulting and seismicity

As discussed in Section 8.3.5.13, faulting and seismicity could potentially shear waste canisters in regions of enhanced downward moisture flux, create enhanced-permeability zones, or cause structural or stress changes that cause the water table to rise. The site characterization penetrations will not occur in waste emplacement areas and are moreover not expected to be preferential pathways because of the backfill and seals. If faulting should cause the water table to rise enough to saturate the repository horizon, the ground-water flow in the saturated zone at the repository horizon probably would be predominantly lateral, following the regional ground-water flow system. The penetrations would not be expected to be preferential pathways because the shafts and boreholes would be vertical penetrations in a lateral flow system. The penetrations could enhance vertical mixing if radionuclides entered the holes; this probably would enhance performance. Therefore, the DOE judges that, given the occurrence of faulting and seismicity, performing site characterization activities described in this document will not preclude meeting the total system release performance objective.

Magmatic intrusion

As discussed in Section 8.3.5.13, magmatic intrusion into the unsaturated zone would probably affect the distribution and magnitude of ground-water flux, change rock hydrologic properties, and change geochemical properties. Site characterization penetrations that encounter perched water above a magma intrusion would be laterally separated from waste-emplacement areas and would drain small amounts of water due to the borehole seals. This is similar to what would happen if penetrations intersected the saturated fracture. The other effects produced by magmatic intrusion would be independent of the presence of site characterization penetrations or effects. Consequently, the DOE judges that, given the occurrence of magmatic intrusion, performing site characterization activities described in the document will not preclude meeting the total-system performance objective.

Extrusive magmatic activity

Section 8.3.5.13 describes a potential disruptive scenario in which a volcano erupts through the repository and contents of a waste package are borne upward by extruding magma. The effects produced by this scenario would be independent of the presence of site characterization penetrations or effects. The DOE can ascertain no credible manner by which site characterization activities could preclude meeting the total-system performance objective, assuming the occurrence of this scenario.

Irrigation

Section 8.3.5.13 considers an increase in moisture flux through the repository as a result of irrigation in Midway Valley. Site characterization penetrations in these postulated areas of Midway Valley would not be expected to be preferential pathways because of the presence of backfill and borehole seals. In addition, boreholes will be laterally separated from the waste-emplacement areas. Therefore, the DOE judges that, given the occurrence of irrigation, performing the site characterization activities described in this document will not preclude meeting the total system release performance objective.

Intentional ground-water withdrawal

Section 8.3.5.13 considers changes to ground-water recharge, water-table lowering, dewatering below the repository, and increased hydraulic gradients in the saturated zone. With the exception of ground-water recharge, as discussed in the irrigation scenario, these scenarios primarily affect the saturated zone; the hydrologic characteristics of the unsaturated zone will not be significantly affected. Therefore, site characterization activities in the unsaturated zone, given the occurrence of intentional ground-water withdrawal, will not preclude meeting the total system release performance objective.

Exploratory drilling

Section 8.3.5.13 considers exploratory drilling that occurs after the repository has been closed. Such drilling could potentially intercept waste

and bring it to the surface with cuttings, introduce water by future drilling, create preferential pathways by drilling, and introduce chemicals (surfactants) that enhance water movement. Impacts of exploratory drilling after repository closure are independent of the site characterization activities. Therefore, the DOE judges that, given the occurrence of exploratory drilling after repository closure, the site characterization activities described in this document will not preclude meeting the total system release performance objective.

Resource mining

Section 8.3.5.13 considers resource mining that could potentially intercept waste and bring it to the surface, introduce water to the repository, create a preferential flow path, or change hydrologic characteristics by introducing surfactants. The impacts of resource mining after repository closure are independent of the site characterization activities. Therefore the DOE judges that, given the occurrence of resource mining after repository closure, the site characterization activities described in this document will not preclude meeting the total system performance objective. In addition, site characterization would not increase the probability of resource mining. None of the materials that would remain at the site after site characterization (e.g., concrete, dilute aqueous tracers, borehole casing, instrumentation) are likely to be interpreted as geochemical indicators that might lead to exploratory mining.

Climate control

Section 8.3.5.13 considers effects of climate control; these effects could potentially increase percolation through the repository, raise the water table to the repository level, or perch water above or below the repository. Changes in the site due to climate control will be similar to changes from the disruptive scenarios resulting from extreme climate change. The evaluations are similar, and a similar conclusion is made that performing site characterization activities will not preclude meeting the total system performance objective.

Surface flooding or impoundments

Section 8.3.5.13 considers disruptive scenarios produced by potential surface flooding or surface-water impoundments. In these scenarios, groundwater flux is presumed to be increased beneath a wash during a flood or beneath a surface-water impoundment, allowing water to seep into boreholes or shafts.

The site characterization penetrations that might affect performance because of flooding include both site characterization drillholes and exploratory shafts. Two exploratory shafts will be constructed, and approximately 30 boreholes may be drilled to the repository depth within the repository drift boundary. According to current plans, both boreholes and shafts will be backfilled and sealed (Fernandez et al., 1987). Figure 8.4.3-2 shows a schematic of the sealing concepts for the exploratory shafts.

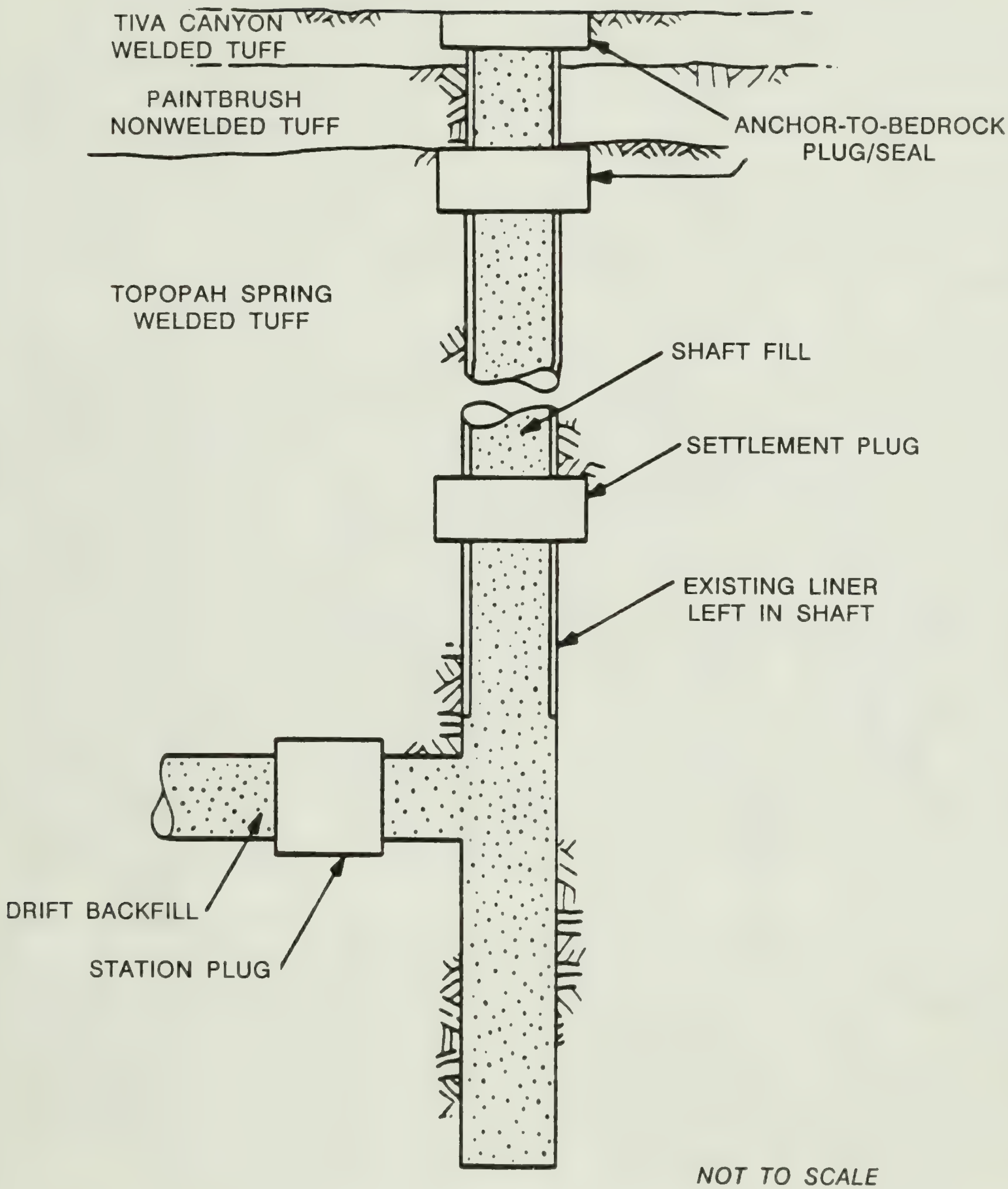


**Figure 8.4.3-2.** Sealing concepts for the exploratory shafts.

Two sets of analyses have investigated effects of flooding on the hydrology of the unsaturated zone due to the presence of an exploratory shaft. Peters (1988; see topic 2 in Section 8.4.3.2.1.1) investigated effects of ponding water on a highly permeable feature (such as a backfilled shaft) in Yucca Mountain for over two days. Their analyses showed that there was no effect on percolation at the proposed repository horizon during the first 1,000 years following the event; the percolation rate only doubled during the time period between 10,000 and 100,000 years. The analyses indicate that a large fraction of the water that moves through a highly permeable material in the unsaturated zone will be gradually imbibed into the matrix material. In these analyses, only a small amount of the initially ponded water penetrated to the repository horizon.

Fernandez et al. (1988) analyze water flow in the backfilled exploratory shafts for flow scenarios that assume the occurrence of a probable maximum flood (PMF) (Table 11 of Bullard, 1986). The analysis provided a reasonable upper bound to the total water entry into the backfilled exploratory shafts through fractures in the boreholes. Figure 8.4.3-3 (taken from Fernandez et al., 1988) shows topographic cross-sections in the vicinity of the current ES-1 and ES-2 locations with the PMF level indicated. As can be seen from the figure, the proposed locations of the shafts are at a higher elevation than the estimated PMF water level, even considering debris. Furthermore, erosion at the shaft location is not expected to lower the ground level below the elevation of the PMF. The exploratory shafts are collared in the Tiva Canyon Member where the potential for erosion of alluvium around the shaft collar is very low. Typical erosion rates expected for hard-rock areas of Yucca Mountain of between 0.8 and 4.7 cm per 1,000 years are given in Table 1-2 of Section 1.1.3.3.1 of this SCP. Maps of the PMF flood channel, including debris flow (Fernandez et al., 1988), show that the surface location of the ESF is 5 m above this flood level at the ES-1 location and 11 m at the ES-2 location. Because of the low erosion rates and the physical separation of the exploratory shaft from the PMF flood channel, erosion is not expected to have an impact on the analyzed scenarios for at least 10,000 years.

A further indication of the low likelihood that flood waters will reach the exploratory-shaft locations is shown in Table 8.4.3-1 (taken from Fernandez et al., 1988). The table lists comparative flood peak discharges in the Yucca Mountain area. The computed peak discharges required to reach the ES-1 and ES-2 are approximately 45 and 240 times, respectively, the amounts of the estimated PMF discharge. Given the same antecedent conditions and drainage area, these extreme peak discharges would require an equivalent increase in the magnitude of precipitation over approximately the same time period. Fernandez et al. (1988) conclude that the likelihood that flood waters will enter the exploratory shafts from the surface is small.

The flood scenario analyzed by Fernandez et al. (1988) for the current locations of the exploratory shafts (Section 8.4.2.2.1) depicts fracture flow, originating at the surface from flooding, intercepting the shafts and associated zones of modified permeability due to fracturing around the shafts anywhere below the surface. The exploratory shafts will be constructed using a smooth-wall blasting technique to limit damage to the rock formation (Section 8.4.2.2). Because the shafts are collared in bedrock and are located outside of the PMF storm channels and valley fill alluvium, water is

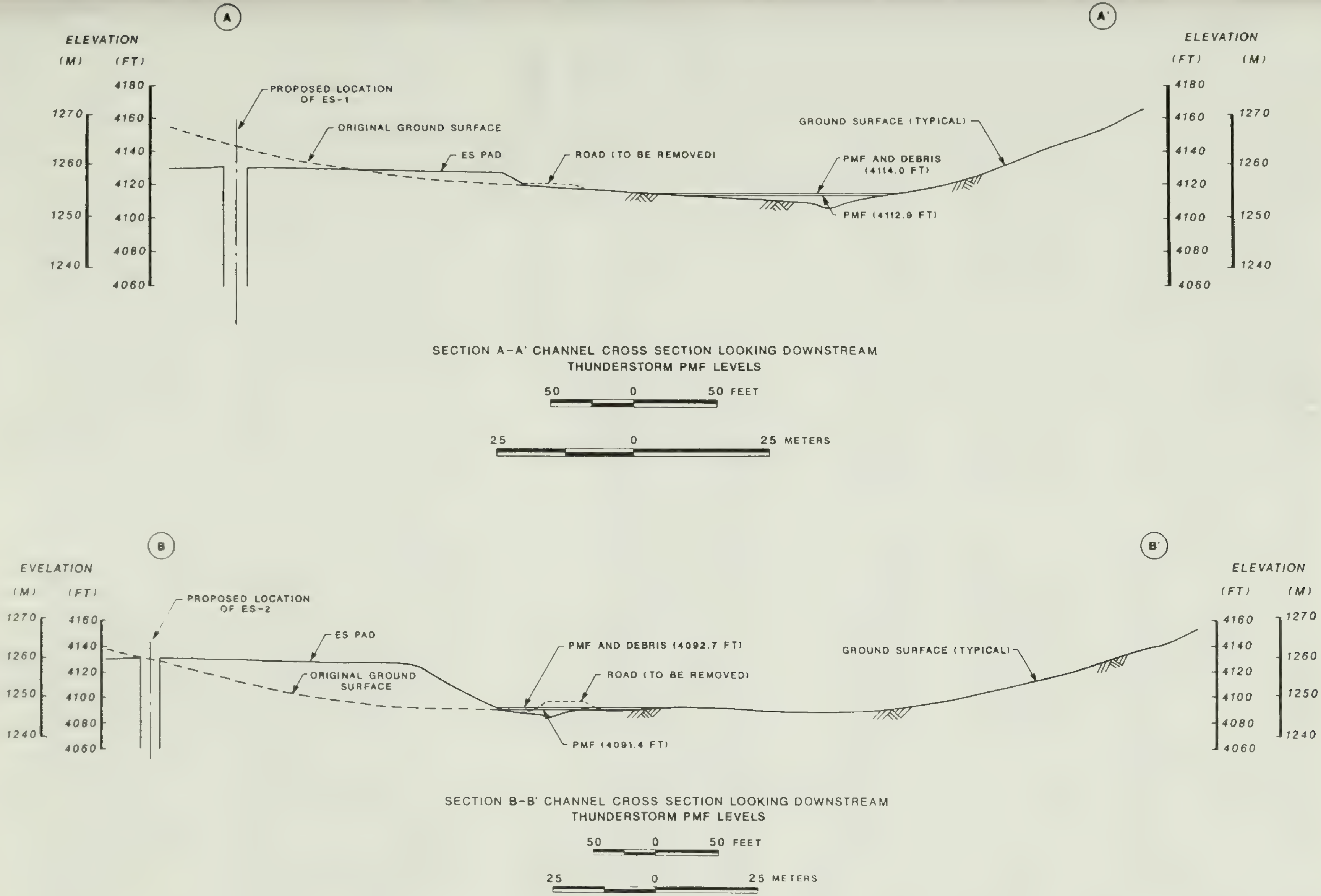


**Figure 8.4.3-3.** Topographic cross sections in the vicinity of exploratory shafts 1 and 2 locations.

Table 8.4.3-1. Comparative flood peak discharges in Yucca Mountain area

| Wash | Drainage area ($mi^2$) | Peak flood discharge (cfs) |
|---|---|---|
| Fortymile | 312 | 540,000[a] |
| Busted Butte | 6.6 | 44,000[a] |
| Drill Hole | 15.4 | 86,000[a] |
| Yucca | 16.6 | 92,000[a] |
| Coyote | 0.2 | 3,350[b] |
| Coyote - discharge to reach exploratory shaft-1 collar | 0.2 | ~150,000[c] |
| Coyote - discharge to reach exploratory shaft-2 collar | 0.2 | ~820,000[d] |

[a]From Squires and Young (1984) for the regional maximum flood.
[b]From Bullard (1986) for thunderstorm probable maximum flood (PMF).
[c]Computed peak discharge to reach exploratory shaft-1 collar (>45 times PMF discharge).
[d]Computed peak discharge to reach exploratory shaft-2 collar (>240 times PMF discharge).

not expected to enter the exploratory shafts directly from the surface but could enter the shaft below the surface from, for example, water flow in fractures. To be conservative, a fracture network was assumed to occur below the surface and to communicate easily within the entire drainage basin, and water was not assumed to be imbibed into the unsaturated matrix tuff. These conditions allowed a greater volume of water to enter an exploratory shaft than may be reasonably expected. The analysis assumed that in a PMF all the rainfall infiltrates into the ground either uniformly or over the more restricted area defined by the existing water courses. For these two cases, the total amount of water entering the exploratory shafts was estimated to be 1,250 $m^3$ and 1,320 $m^3$ (330,000 gallons and 350,000 gallons). This calculation assumed no runoff or water imbibition from the fractures into the matrix. If allowance is made for runoff and imbibition, then the total water volume entering the exploratory shafts was estimated to be reduced by one to two orders of magnitude, or 10 to 100 $m^3$ (2,600 to 26,000 gallons) of water. The presence of shaft seals would reduce these volumes even further.

Fernandez et al. (1988) indicate that even the conservative estimated volume of approximately 1,300 $m^3$ of water entering the backfilled exploratory shafts at the present locations is well within the drainage capability of the exploratory shaft facility. Given the lateral separation of the shafts from waste-emplacement areas and this analysis, Fernandez et al. (1988) concluded that no water is expected to enter the immediate repository environment or to contact the waste packages. The ESF has been designed to drain any water entering the main test level away from potential waste-emplacement areas (i.e., toward ES-1).

Because boreholes are much smaller than the exploratory shafts, the quantity of water entering a borehole from a flooding event would be smaller than that just discussed. Boreholes also will be drilled when practicable so that a buffer of approximately 30 m or more exists between the borehole and emplaced waste (Section 8.4.2.2.1).

On the basis of the above discussions, the DOE judges that given the occurrence of flooding events, the site characterization activities described in this document will not preclude meeting the total-system performance objective.

Regional changes in tectonic regimes

Section 8.3.5.13 considers regional changes in the tectonic regime that could potentially raise or lower the water table. Events and processes that could raise or lower the water table are discussed above under extreme climate changes. The evaluations are similar and a similar conclusion is made. Therefore, the DOE judges that, given the occurrence of regional changes in tectonic regimes, the site characterization activities described in this document will not preclude meeting the total system release performance objective.

Folding, uplift, and subsidence

Section 8.3.5.13 considers events of folding, uplift, and subsidence that could potentially change percolation flux values or lower the underground facility with respect to the water table. As indicated in previous discussions, site characterization activities are not expected to preclude the site from meeting the total system release performance objective in the event of a change in percolation flux. Lowering the underground facility with respect to the water table will have essentially the same effect as raising the water table, which was discussed under extreme climate changes. Thus, the DOE judges that site characterization activities, given the occurrence of changes in the water table elevation, will not preclude meeting the total system release performance objective.

Summary of conclusions for disruptive scenarios

As indicated previously, this section considers whether, given the occurrence of the disruptive scenario, the potential impacts of the scenario will change site conditions such that the site characterization activities will preclude the capability of the site to meet the total systems release performance objective. In some scenarios (i.e., extreme climatic change, stream erosion, faulting and seismicity, magnetic intrusion, irrigation,

climate control, surface flooding or impoundments, regional changes in tectonic regimes, and folding, uplift, and subsidence), one of two major potential impacts is expected. Either the flux through the unsaturated zone would increase such that saturated flow conditions could exist in fractures, or perched water could occur at rock unit contacts with distinct permeability contrast. Site characterization penetrations could then potentially function as localized, preferential drainage points for fractures or perched-water zones above the repository or as localized preferential pathways for gaseous or liquid-phase releases from the repository horizon. To the extent that site characterization activities within the conceptual perimeter drift boundary penetrated the Calico Hills formation, those penetrations could locally reduce the effectiveness of the primary barrier for waste isolation. In other scenarios (e.g., extrusive magnetic activity, exploratory drilling, and resource mining), there does not appear to be any significant relationship between the site characterization activities and the exhumation of wastes or creation of preferential pathways by those scenarios. In addition, the scenario of intentional ground-water withdrawals does not appear to have any significant relationship with the site characterization activities.

As in the expectations for effects under present site conditions, the lateral separation of the site characterization penetrations from the waste emplacement areas, the drainage of the ESF internally to the sump for ES-1, and the sealing of the site characterization penetrations should ensure that these penetrations are neither preferential drainage points nor preferential pathways for gaseous or liquid-phase releases (Section 8.3.3.1). If there is a need to penetrate the Calico Hills unit with a shaft and drifts, further analysis will be needed to determine the potential impacts of these currently deferred site characterization activities on the primary barrier for waste isolation.

In summary, the performance of the site characterization activities as planned is not expected to preclude the capability of the site to meet the postclosure performance objective for total systems release of radionuclides to the accessible environment over the 10,000-yr period of performance. In the absence of further site characterization and analysis, site characterization activities are also not reasonably expected to significantly affect either the frequency of occurrence or the magnitude of the disruptive scenarios that may be reasonably postulated to occur within the 10,000-year period of performance.

Conclusion

The potential impacts to performance from the site characterization activities have been evaluated under assumptions of the occurrence of the nominal scenario; changes resulting from likely processes and events and changes resulting from disruptive scenarios were considered. The principal focus of the evaluations was on the potential for increased ground-water flux and for penetrations resulting from site characterization activities to function as preferential pathways for liquid water movement. The DOE judges that no significant impacts to performance will be caused by having performed the site characterization activities described in Section 8.4.2.

8.4.3.3.2 Impacts on waste package containment

The issue resolution strategy to achieve and demonstrate that the substantially complete containment performance objective for the waste package is met is summarized in the first part of this section. The second part of this section evaluates the impacts on the waste package containment of site characterization activities. The impacts are evaluated by considering the effects of hydrological, geochemical, and thermal/mechanical changes from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities on the system elements relied upon for container performance. The system elements that are relied upon are the postemplacement environment of the waste package, the waste container and its properties under these environmental conditions, and the waste form and its properties under these environmental conditions. An evaluation of site characterization activities on applicable design criteria from 10 CFR Part 60 and their implications on postclosure performance of the waste package container are also given.

8.4.3.3.2.1 Issue resolution strategy

This section discusses containment requirements for the waste package and the effects of the construction of the ESF and of testing on the waste package. Issue 1.4 (Section 8.3.5.9) addresses the performance of the waste package as required by 10 CFR 60.113. The performance objective for containment is as follows: "The engineered-barrier system shall be designed, assuming anticipated processes and events, so that containment of high-level waste (HLW) within the waste package will be substantially complete for a period to be determined by the Commission, taking into account factors specified in 60.113(b), provided that such a period shall not be less than 300 yr nor more than 1,000 yr after permanent closure of the geologic repository."

For the purposes of this discussion, the waste package is defined, in 10 CFR 60.2, as "the waste form and any containers, shielding, packing and other absorbent materials immediately surrounding an individual waste container." Chapter 7 contains graphic representations of typical waste package configurations, identifying specific waste package components.

The DOE understands substantially complete containment to mean that the set of waste packages will fully contain the total radionuclide inventory for a period of 300 to 1,000 years following permanent repository closure, allowing for recognized technological limitations. Implementation of this understanding will be based solely on reliance on the waste package as the major component of the engineered barrier system. The container is the primary barrier of the multiple barrier system for the purpose of containment of radionuclides. The waste package will be designed to resist the degrading effects of the repository environment under anticipated processes and events. Containment will be based on the ability of the waste package, by virtue of its intrinsic properties and designs, to maintain a continuous, sealed barrier around the waste.

The DOE expects that demonstrating compliance with the regulation governing the performance of the waste package during the containment period will be best achieved by minimizing the residual uncertainties. The residual uncertainties in predicting performance are due to three factors: (1) the inherent limitations associated with manufacturing, handling, and emplacement operations; (2) the uncertainty in developing a complete understanding of the behavior of waste package materials; and (3) the uncertainty in predicting the future environment of each waste package.

These uncertainties can be divided into preclosure and postclosure considerations. During the postclosure period, the performance of any waste package cannot be accurately predicted over the long time period of the performance objective because of (1) the problems associated with demonstrating the mechanisms of all possible material degradation models under the range of future environmental conditions and (2) the difficulties in extrapolating short-term experimental data to predict long-term performance. Therefore, it is the goal of the waste-package program to provide for complete containment, allowing for only residual uncertainties. The DOE will minimize the uncertainties associated with the technical limitations for the postclosure period through a defense-in-depth concept. This concept introduces conservatism in demonstrating waste package performance through bounding assumptions, using multiple barriers to limit container degradation and waste form releases, and evaluating alternative materials and designs.

The DOE has developed a performance allocation process that is the basis for the testing program. The performance allocation process identifies the system elements that contribute to the demonstration of substantially complete containment and that provide assurance that releases of high-level waste occur at very low rates. These elements include the engineered environment, the waste containers, and the waste forms. However, the emphasis on providing containment is placed on the waste container.

To resolve this issue, the DOE will use the following approach to develop the engineered barrier system:

1. Enhance the natural features of the unsaturated zone repository.

2. Evaluate waste package container design to provide a highly reliable sealed containment barrier.

3. Evaluate alternative design concepts and materials.

4. Execute a thorough testing, evaluation, and characterization program.

5. Fabricate and close waste package containers using detailed specifications and procedures.

6. Identify uncertainties that influence performance predictions, quantify or bound the uncertainties, and then reduce them to a practical minimum through testing and performance confirmation.

7. Use the characteristics of the waste form in conjunction with the other engineered waste package components and with the unsaturated

zone environment to ensure that any releases that may occur during the containment period occur at low rates.

In terms of minimizing uncertainties, appropriately combining uncertainty and sensitivity analyses will allow the modeling effort to feed information back to the design/testing effort regarding priorities in reducing those uncertainties that can be experimentally addressed. The iterative nature of this issue resolution strategy becomes evident in identifying those sources of important uncertainties that might be reduced through experimental or design changes. Section 8.3.5.9 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.4.

#### 8.4.3.3.2.2 Impacts on waste package containment

The system elements relied upon for container performance are the engineered environment of the waste package, the waste container, and the waste form. This section discusses the potential impacts on these elements of hydrological, geochemical, and thermal/mechanical changes from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities of site characterization.

This section also evaluates the effects of site characterization activities on the design criteria of 10 CFR 60.133, 60.134 and 60.135, and the implied effects on postclosure performance of the waste package container. The design criteria considered in evaluating the impacts on the waste package containment are

1. 10 CFR 60.133(a)--General criteria for the underground facility.
2. 10 CFR 60.133(b)--Flexibility of design.
3. 10 CFR 60.133(d)--Control of water and gas.
4. 10 CFR 60.133(e)--Underground openings.
5. 10 CFR 60.133(f)--Rock excavation.
6. 10 CFR 60.133(h)--Engineered barriers.
7. 10 CFR 60.133(i)--Thermal loads.
8. 10 CFR 60.134--Design of seals for shafts and boreholes.
9. 10 CFR 60.135(a)--High-level-waste package design in general.

<u>Engineered environment</u>

The three performance measures for the engineered environment of the waste package are (1) quantity of liquid water that can contact the container, (2) quality of liquid water that can contact container, and (3) rock-induced load on the waste package.

Quantity of liquid water

Site characterization activities could affect the quantity of liquid water contacting a container during the complete containment period (300 to 1,000 years after permanent closure) by altering the amount and distribution of ground-water flux at the repository horizon, changing the hydrologic

properties of the unsaturated zone (primarily the hydraulic conductivity), or creating preferential pathways for liquid flow.

The unsaturated-zone hydrologic model summarized in Section 8.4.1.3 describes how water moves in fractures and the matrix. According to the model water will not move from the matrix into a waste emplacement borehole unless the matrix is at or near saturation with water. Analyses discussed in Section 8.4.3.2.1.2 show that water moves slowly in the matrix and that a very long time and a large quantity of water are required to saturate the matrix. Section 8.4.3.2.1.2 also describes how the water contained in a fracture is quickly (within hours) imbibed into the matrix. Therefore, it is expected that water in a fracture will be imbibed into the matrix within a few hours after the source of the water flowing into the fracture has stopped.

Surface-related activities are not expected to alter the ground-water flux at the repository horizon, change the hydrologic properties of the unsaturated zone, or create preferential pathways for liquid flow. As discussed in Section 8.4.3.2.5.1, changes to the moisture content of the rock caused by performing surface-related site characterization activities are expected to be transient and to not permanently affect the unsaturated hydraulic conductivity of the near-surface material. Surface-related site characterization activities are not expected to become preferential pathways because the activities are limited to the surface or a few meters beneath the surface. Therefore, surface related activities are not expected to affect the quantity of water that contacts the containers.

As described in Section 8.4.3.2.5.2, drilling activities may cause hydrologic changes within a few meters of the penetrations. These drillholes, where practicable, will be located in columns in the proposed repository, which will be about 2-drift diameters (about 30 m) from the nearest waste package. Should drillholes penetrate waste-emplacement boreholes, these boreholes would not be used for waste emplacement. As discussed in Section 8.4.3.2.5.2, dry drilling methods will be used for boreholes in the conceptual perimeter drift boundary to decrease the potential for fluids to affect in situ hydraulic conditions. The potential hydrologic impacts from drilling activities are evaluated in Section 8.4.3.2.5.2. This evaluation indicated that, because of the construction controls and design features, these activities would not affect the ground-water flux at the repository horizon or create preferential pathways for liquid water flow. Thus, drilling activities should not affect the quantity of liquid water that contacts the container.

During construction of the exploratory shafts and the drifts and alcoves, water will be used for dust control, drilling, and mining. The use of water during construction will be controlled to limit the potential impacts of construction on the site. Most of this water will be removed to the surface by mucking operations. Preliminary estimates indicate that only a small fraction (10 percent) of the water used in the ESF during construction will be retained in the rock mass around the shaft. Because the injection pressure of water introduced during ES construction will be low, the retained water is expected to be a local effect near the shafts. The potential impacts from hydrologic disturbances from the construction of the exploratory

shafts are described in Section 8.4.3.2.5.3, while those from the construction of the drifts and alcoves are given in Section 8.4.3.2.5.4. These evaluations of the hydrologic impacts concluded that constructing the ESF would not affect the ground-water flux at the repository horizon or create preferential pathways for liquid water flow. Therefore, the construction of the exploratory shafts, drifts, and alcoves should not increase the amount of water that contacts containers.

During construction and operation of the ESF, the ventilation system will remove water from the exposed walls in the ESF. As was described in Section 8.4.3.2.1.4, the ventilation system may remove, before waste emplacement, a volume of water comparable to that retained during construction, thereby further reducing any potential for construction water to reach a container in the waste emplacement area of the repository.

ESF testing activities will introduce a very small, controlled amount of water to the unsaturated zone and will affect a relatively small volume of rock in which the moisture distribution will be affected by thermal tests, as discussed in Section 8.4.3.2.5.5. These testing activities will be at least 30 m laterally from the waste emplacement area of the repository. The introduction of water during testing and the movement of moisture by heating will not affect the ground-water flux at the repository horizon or the quantity of water contacting a container.

Thermal/mechanical disturbances may affect the quantity of water contacting a container by providing flow paths and the quality of water by enhancing geochemical changes. Section 8.4.3.2.5 discusses the potential impacts on site characterization activities of thermal/mechanical disturbances. The mechanical disturbances to fracture apertures and hydraulic conductivity from borehole, shaft, drift and alcove construction are expected to be contained within 1 to 2 diameters of the penetrations. The increases in fracture permeability are not expected to create preferential pathways for water to flow to waste emplaced areas because (1) boreholes will be sealed (as described in Section 8.3.3.1); (2) boreholes will be located (where practicable) in pillars laterally separated from waste emplacement areas; and (3) shafts and drifts will be located 30 m laterally from waste emplacement areas. Because of the large distance between the surface-related activities and the repository horizon, no effects on water quantity or quality are expected from these activities. Drilling, exploratory shaft construction, and underground construction of drifts and alcoves will cause mechanical changes in the rock within 1 to 2 diameters of the penetrations. These mechanical changes may increase the fracture permeability within 1 to 2 diameters of the walls. Because of the relatively long distance between these penetrations and areas of waste emplacement, potential increases in fracture permeability are not expected to create pathways for water to flow to waste-emplacement boreholes and thus affect the quantity of water that contacts a container.

Quality of liquid water

The quality of liquid water that can contact a container is also a performance measure for the engineered environment. For site characterization activities to affect the quality of water that can contact a container, there must be (1) a source of chemical change, (2) a pathway for

these chemical changes to reach a container, and (3) a mechanism for transport of the chemicals to the container. During site characterization activities, fluids and materials will be introduced to the surface and into the ESF that may be a source of chemical change. Section 8.4.3.2.5 discusses the potential geochemical impacts from five·types of site characterization activities.

As discussed in that section, the potential geochemical disturbances from fluids and materials introduced onto the site surface and into the underground facilities will be local and not transported far from the source. Construction controls on the amount and use of chemicals also decrease the potential geochemical disturbances to the site. During construction of the ESF, fluids and materials will be introduced into the unsaturated zone. West (1988) tabulated the amounts of fluids and materials and evaluated the potential interactions between them. Because of the expected relatively short distance the fluids would penetrate the rock wall and the approximately 30 m lateral distance from the shafts, drifts, and alcoves to waste emplacement areas in the repository, the fluids and materials from ESF construction are not expected to affect the waste package environment or change the quality of water contacting the container. Therefore, site characterization activities should not cause geochemical disturbances that would affect the ground-water flux at the repository horizon or create preferential pathways for liquid flow that could affect the quality of water contacting a container.

Rock-induced loads

Rock-induced loads on the waste package is the third performance measure for the engineered environment. For site characterization activities to affect the rock-induced loads on the waste package, they should enhance rock block movement due to the rock responding to gravitational forces and thermal cycles. Section 8.4.3.2.5 discusses potential impacts on site conditions from thermal/mechanical disturbances.

The surface-related activities are not expected to produce enough rock movement to affect the rock-induced loads on the waste package, because the shallow depth of those activities leaves hundreds of meters of undisturbed-vertical rock between them and waste emplacement. Drilling activities and exploratory shaft construction are not expected to enhance rock movement and promote rock-induced loads on the waste package because of the approximately 30 m of lateral distance between these activities and areas of waste emplacement. Also, the limited number of these penetrations would decrease the potential for these activities to affect rock-induced loads. The drilling activities will, to the extent practical, be located in pillars in the proposed repository or kept a distance of 30 m away from areas of waste emplacement.

The underground construction of drifts and alcoves as part of the ESF also should not enhance block movement and affect rock-induced loads on the waste package because the excavation will meet the same general standards as will be used in the remainder of the underground facility. Hill (1985) analyzed the structural stability of a conceptual model of the ESF main test level and concluded that drifts had to be closer than one-half drift diameter to affect an adjacent drift. The underground construction of alcoves also is not expected to enhance block movement and affect rock-induced loads on the

waste package because of the long horizontal distance from the alcoves to areas of waste emplacement. ESF testing activities are not expected to enhance block movement from gravitational forces or thermal cycles. The tests introducing heat into the rock are at least 30 m from areas of waste emplacement and, as discussed in Section 8.4.3.2.5.5, the thermal effects from these tests are not expected to affect rock at this distance.

Waste container

The performance measure for the waste container is the fraction of containers that have failed. (Failure is defined as a breach allowing air flow of $1 \times 10^{-4}$ atm-cm/s.) For site characterization activities to affect the failure of containers they would need to affect the number of containers that are contacted by water contacts or the rock-induced loads on the container. As discussed for the engineered environment, site characterization activities are not expected to develop preferential pathways, enhance the quantity of liquid water contacting a container, or enhance rock block movement. Therefore, site characterization activities are not expected to affect the fraction of containers that have failed.

Waste form

The performance measure for the waste form is the cumulative release of radionuclides from the ensemble of breached packages. For site characterization activities to enhance the cumulative release of radionuclides from breached packages, they would have to provide water to the waste-emplacement boreholes or create preferential pathways. As discussed for the engineered environment, site characterization activities are not expected to affect the quantity of water that contacts waste packages or to provide preferential pathways. Therefore, these activities should not affect the cumulative release rate of radionuclides from the ensemble of breached packages.

In summary, site characterization activities will not affect the performance measures of the system elements that are relied upon for container performance as specified by 10 CFR 60.113(b).

### 8.4.3.3.2.3 Impacts of site characterization activities on waste package design features

The ESF is designed with features that will enhance the capability of the waste package to meet the performance objective for containment of 10 CFR 60.113. These design features are itemized in Section 8.4.3.2.4. The potential effects of site characterization activities on the ability to meet applicable design criteria and the implications on postclosure performance of the waste package are discussed in the remainder of this section.

Section 60.133(d) (control of water and gas) states that the design of the underground facility shall provide for control of water or gas intrusion. The ESF has been designed to permit natural drainage of free water to the sump in ES-1. Other mechanisms through which an underground facility design could assist in achieving the performance objectives include material control. Controlling water during construction and carefully selecting and

controlling the quantities and types of materials that could chemically interact with the waste container or waste form materials also will help prevent containment and isolation degradation. None of the five types of site characterization activities will impact this design criteria nor will they have adverse affects on the postclosure performance of the waste package container.

Sections 60.133(e) and 60.133(f) are concerned with the creation of fractures and potential flow paths for radionuclide migration. These criteria are specifically concerned with the opening or creating of fractures in the overlying or surrounding rock that could lead to the creation of potential flow and migration paths to the accessible environment. The construction of the exploratory shaft and the drifts and testing alcoves will use control blasting procedures, as well as extraction ratios and drift-span dimensions that are consistent with current repository design. These site characterization activities will not impact the ability to comply with these design criteria nor will they have adverse affects on the postclosure performance of the waste package container.

Section 60.133(h) (engineered barriers) is concerned with the EBS being designed to assist the geologic setting in meeting the performance objectives for the period following permanent closure. The location of the repository in the unsaturated zone has led to design considerations to limit the amount of water contacting the waste package. The repository has been designed to permit natural drainage of free water to the lowest point of the repository. The temperature of the waste canister also contributes to containment. An air gap between the host rock and waste containers may be used to further reduce the contact of water with the waste package. The five categories of site characterization activities should not impact the ability to meet this design criterion or have adverse effects on postclosure performance of the waste package container.

Section 60.133(i) (thermal loads) is concerned that the postclosure waste disposal system must use a thermal loading that does not preclude meeting the performance objective. The design goal is to maintain a thermal load that is low enough not to lead to tectonic or hydrologic impacts on compliance. None of the site characterization activities should affect the thermal loads on the repository.

The additional design criteria for the underground facility (10 CFR 60.133) that have implications for the postclosure performance of the waste container were identified at the beginning of this section. These criteria include Section 60.133(a), which requires that the underground facility and the engineered barrier system be designed to contribute to containment and isolation of radionuclides, and Section 60.133(b), which requires that the underground facility be designed with flexibility to allow for adjustments to accommodate specific site conditions. The underground facility has been designed to drain water away from emplaced waste and to maintain a lateral separation distance between the ESF and emplaced waste. None of the five types of site characterization activities should have an impact on meeting these design criteria or effects on postclosure performance of the waste package container.

Section 60.134 has implications that the seals for shafts and boreholes are selected to reduce the potential for creating preferential pathways for ground-water to contact waste packages or for radionuclide migration. Boreholes and shafts will be sealed so that surface and ground water will not preferentially move into the penetrations and affect the hydrologic conditions at the repository horizon and so that preferential pathways are not created. Site characterization activities should not impact the capability to seal boreholes and shafts or influence the effects of seals on postclosure performance of the waste package container.

Section 60.135(a) states that the waste package and its interactions with the emplacement environment should not compromise the functions of the waste packages. The effects of site characterization activities on the emplacement environment are being limited by the controls on the use of fluids and materials and on construction. These controls should cause no effects on the emplacement environment and, thus, no effects on the waste package design. Site characterization activities will not have an impact on the waste package or on the postclosure performance of the waste package container.

### 8.4.3.3.3 Impacts on engineered barrier system release

The issue resolution strategy to achieve and demonstrate compliance with the performance objective for controlled radionuclide releases from the EBS is summarized in the first part of this section. The second part of this section evaluates the impacts of site characterization activities on releases from the engineered barrier system. The impacts are evaluated by considering the effects of hydrological, geochemical, and thermal/mechanical changes from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities on the system elements relied upon to limit releases from the EBS. The system elements that are relied upon are the engineered environment, the container, and the waste form. The effects of site characterization activities on the ability to meet applicable design criteria from 10 CFR Part 60 and their implication on the postclosure performance objective related to the EBS release rate are also evaluated.

#### 8.4.3.3.3.1 Issue resolution strategy

This section discusses the postclosure performance objective related to the engineered barrier system (EBS) release rate and the impact of the construction and testing in the ESF on the releases from the EBS. Issue 1.5 (Section 8.3.5.10) addresses the performance of the EBS as required by 10 CFR 60.113(a)(1)(ii). This regulation states, in part, that the EBS shall be designed, assuming anticipated processes and events, so that "(B) the release rate of any radionuclide from the engineered barrier system, following the containment period, shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided that this requirement

does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay."

The essence of the waste package strategy lies in an iterative process of performance allocation, performance assessment, and testing to determine if the goals are met. If the objective cannot be met, changes are made in design, materials, etc., and the process is repeated until the design objectives are met with reasonable assurance.

The strategy for resolution of Issue 1.5 is based on the present knowledge of the repository emplacement environment, the data gathered on waste-form performance in environments that can be related to the projected repository environment, and the use of models to assess the performance of various system elements. The system elements relied upon to limit releases are (1) the engineered environment, which limits the quantity and quality of water that can contact the containers and limits the rock-induced load on the waste package; (2) the container, which controls the fraction of containers that have breached and the fractional release due to mass-transfer resistance of breached containers (and cladding); and (3) the waste form, which controls the release fractions or rates from waste components. Strategies are developed for the expected case in which the amount of liquid water contacting the waste form is negligible and for a bounding case that allows 20 L/yr to contact waste forms in up to 10 percent of the waste packages. Two alternate approaches for liquid releases are included in the strategy in the event that the amount of liquid from the reference design is not low enough to meet the requirements of 10 CFR 60.113. The first approach is to take credit for other components and processes that limit access of water to spent fuel. The second approach is to take credit for the possible contribution of the rock in the EBS in limiting release (contingent on an interpretation through a mechanism such as rulemaking that the EBS can include a portion of the host rock).

Current data presented in Section 7.4.3 indicate that it is very likely that the performance objective for control of the release rate from the EBS can be met by the waste forms in an unprotected condition provided that the analysis is done using the conditions of the expected case. For the bounding case, the performance objective can be met, provided credit can be taken for the fraction of waste packages where the waste form is not contacted by water, for mass-transfer resistance of breached containers, and for cladding. This resistance to release of radionuclides can be provided by breached containers and cladding, even in their degraded condition. The limitation of wetted waste forms to 10 percent of the total depends on environmental and engineered elements. The existing information is not sufficient to allow a final selection of the components and performance measures. Section 8.3.5.10 provides a detailed discussion of the regulatory basis and resolution strategy for Issue 1.5.

8.4.3.3.3.2 Impacts on engineered barrier system release

The system elements relied upon to limit releases from the EBS following the containment period are the engineered environment, the container, and the waste form. The system elements, and the performance measures, relied upon to limit releases from the EBS are the same elements relied upon to demonstrate compliance with the container lifetime presented in Section 8.4.3.3.2.2, and that discussion will not be totally repeated here. This section also evaluates the effects of site characterization activities on the design criteria of 10 CFR 60 and the implications of the effects on post-closure performance of the EBS release. The design criteria considered in evaluating the impacts on the EBS release are

1. 10 CFR 60.133(a)--General criteria for the underground facility.
2. 10 CFR 60.133(b)--Flexibility of design.
3. 10 CFR 60.133(d)--Control of water and gas.
4. 10 CFR 60.133(e)--Underground openings.
5. 10 CFR 60.133(f)--Rock excavation.
6. 10 CFR 60.133(h)--Engineered barriers.
7. 10 CFR 60.133(i)--Thermal loads.
8. 10 CFR 60.134--Design of seals for shafts and boreholes.
9. 10 CFR 60.135(a)--High-level-waste package design in general.

Engineered environment

The performance measures for the engineered environment for the EBS release following the containment period are the quantity and quality of liquid water that can contact a container and the rock-induced load on the waste package. For site characterization activities to affect the quantity of water that can contact a container, they must provide a source of liquid water and a flow path for liquid water. For site characterization activities to affect the EBS release after the containment period, the effects would have occur at least 300 years after permanent closure, i.e., they would have to be permanent, rather than transient, effects. During this period, the thermal pulse from the emplaced waste would initially move water from near the EBS into the cooler host rock. As discussed for container lifetime in Section 8.4.3.3.2.2, the site characterization activities are not expected to provide a source of increased flux or a preferential flowpath during the containment period that will change the quantity of water that contacts a waste package. Because the source of, and flowpaths for, liquid water would be similar after containment, no site characterization activities are expected to change the quantity of liquid water that can contact a container.

As discussed in Section 8.4.3.3.2.2, site characterization activities may cause mechanical changes within 1 to 2 diameters of penetrations. Because the distance between the construction of penetrations and the waste emplacement areas in the repository is greater than the expected range of mechanical changes, such changes are not expected to create preferential pathways for water to flow to waste emplacement boreholes and to affect the quantity of water that contacts a container. Therefore, no effects on the quantity of water contacting a container are expected from surface-related activities, drilling activities, exploratory shaft construction, underground construction of drifts and alcoves, or ESF testing activities.

The quality of water that can contact a container during the controlled release period is also a performance measure for the engineered environment. To affect the quality of water, there must be a source of chemical change, a pathway for these chemical changes to reach a container, and transport of the chemicals to the container. As discussed in Section 8.4.3.3.2.2 for the containment period, the chemicals would need to be transported 30 m laterally to contact a container. The current model of Yucca Mountain suggests that ground-water flux is predominantly vertical in the unsaturated zone, which should limit the lateral movement of water and the transport of chemicals to waste emplacement areas of the repository.

As discussed in Section 8.4.3.3.2.2, no enhanced geochemical changes that could contact a container are expected from thermal effects of site characterization. Therefore, no effects on the quality of water contacting a container are expected for surface related activities, drilling activities, exploratory shaft construction, underground construction of drifts and alcoves, or ESF testing activities.

As discussed for the waste package containment in Section 8.4.3.3.2.2, site characterization activities should not enhance rock block movement due to the rock responding to gravitational forces or thermal cycles. Construction controls limiting the number of penetrations of the unsaturated zone, the standards for construction of the underground facility and the distance from site characterization activities to waste emplacement all help decrease the potential for enhancing rock-block movement.

Container

The performance measures for the container are the fraction of containers that have breached and the fractional release due to mass-transfer resistance of breached containers (and cladding). For site characterization activities to affect these performance measures, the number of containers contacted by water must be affected. To affect the number of containers contacted by water, preferential flowpaths would be required, or the quantity of water available to contact containers would have to be increased. As previously discussed in Section 8.4.3.3.2 hydrological, geochemical, or thermal/mechanical changes from site characterization activities are not expected to affect the ground-water flux at the repository horizon, and thus are not expected to affect the number of containers contacted by water.

Waste form

The performance measure for the waste form is the release fractions or rates from waste form components. The issue resolution strategy considers both liquid and gaseous release. For site characterization activities to affect the liquid release fractions or rates from waste form components inside breached packages, water from site characterization activities would have to contact the waste form. As previously discussed in this section, hydrological, geochemical, or thermal/mechanical disturbances from site characterization activities are not expected to affect the quantity or quality of water available to contact the containers and, therefore, available to contact breached packages and alter the liquid release during the controlled release period.

To affect the gaseous release during the controlled release period, the site characterization activities would have to introduce water in the vicinity of the waste packages or provide preferential pathways to enhance gaseous transport. Boreholes and shafts within the conceptual perimeter drift boundary will be laterally separated from waste emplacement areas and will be sealed so that they will not introduce water in the vicinity of the waste packages. As discussed in Section 8.4.3.2.5.3, the results from Fernandez et al. (1988) suggest that, if the air conductivity of shaft fill was less than about $3 \times 10^{-4}$ m/min, boreholes and shafts would not be preferential pathways for gaseous transport. Therefore, penetrations from site characterization activities are not expected to provide preferential pathways for gaseous transport and affect gaseous releases from the waste form.

In summary, site characterization activities will not affect the performance measures of the system elements that are relied upon for EBS releases as specified by 10 CFR 60.113(a)(1)(ii).

The ESF is designed with features that will enhance the capability of the EBS to meet the performance objective for the release rate of radionuclides of 10 CFR 60.113. These design features are itemized in Section 8.4.3.2. The design criteria of 10 CFR Part 60 that have implications for the postclosure performance of the EBS releases were identified at the beginning of this section. Because the implications of the design criteria on the postclosure performance of the EBS are identical to the implications on postclosure performance of the waste package containment (Section 8.4.3.3.2.2), they will not be repeated here.

## 8.4.3.3.4 Impacts on ground-water travel time

### 8.4.3.3.4.1 Issue resolution strategy

One of the four postclosure performance objectives described in 10 CFR Part 60, Subpart E addresses pre-waste-emplacement ground-water travel time (GWTT) and places a minimum criterion of 1,000 yr for ground-water travel time from the disturbed zone to the accessible environment along the fastest path of likely radionuclide travel. The disturbed zone has been defined in 10 CFR Part 60 as "that portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes." The definition for underground facility in 10 CFR Part 60 excludes shafts, boreholes, and their seals.

The ability to meet this performance objective depends upon the characteristics of the flow system at the Yucca Mountain site. The current understanding of this system is described in Chapter 3 and is summarized in Section 8.4.1 for the purpose of evaluating the impacts of site characterization. On the basis of this current understanding, a strategy for meeting the GWTT performance objective has been developed.

Section 8.3.5.12 (Issue 1.6) describes the DOE's issue resolution strategy for determining the degree of compliance with the GWTT performance objective. The strategy is developed using the pre-waste-emplacement (liquid) ground-water travel time for each hydrogeologic unit from the disturbed zone to the accessible environment as the performance measure. The unsaturated Calico Hills nonwelded unit has been designated as the primary barrier. This unit was chosen as the primary barrier because preliminary calculations have estimated the average GWTT through the unit to be greater than 10,000 yr (Sinnock et al., 1986). The issue resolution strategy proposes that the pre-waste-emplacement ground-water travel time be calculated for the current hydrological and geological conditions at the site; i.e., before any significant disturbance of the site. Based on the intent of the GWTT performance objective, as discussed above, any significant changes to the site conditions will not be included in the calculation of the GWTT performance measure, except in the manner that those changes affect the definition of the disturbed zone. Therefore, the evaluation of potential impacts to the GWTT performance objective only considers how site characterization activities affect the definition of this boundary.

As discussed in Section 8.4.1, the likely paths for travel of radionuclides carried by ground water are expected to be generally downward through the unsaturated units that underlie the underground facility to the water table and then laterally in the saturated zone to the accessible environment. As explained in Section 8.3.5.12, the DOE expects to rely most heavily on the Calico Hills unit to meet the GWTT performance objective in this case because the current information suggests that the ground-water travel time through this unit is much greater than 1,000 years. The other units in the unsaturated zone and the units in the saturated zone are also expected to contribute to the GWTT.

## 8.4.3.3.4.2 Impacts on ground-water travel time

The strategy in Section 8.3.5.12 conservatively assumes that the disturbed zone extends to 50 m below the emplaced drifts. Langkopf (1987), however, has preliminarily determined the boundary of the disturbed zone to be a plane less than 10 m below the waste-package boundaries. This value is based on evaluations of significant changes to intrinsic hydrologic properties of the rock. The meaning of "significant" was related specifically to the effects on the pre-waste-emplacement GWTT. The determination of the boundary of the disturbed zone considered changes to intrinsic hydrologic properties that could result from repository heating and excavation and considered thermal/mechanical and geochemical effects.

In the following discussions, the potential effects of the categories of site penetrations on the definition of the boundary of the disturbed zone are evaluated.

Surface related activities. The effects on site conditions of the surface related site characterization activities are estimated to extend only to about 10 m below the ground surface. Because the repository horizon is more than 200 m below the surface, these activities are judged not to affect the definition of the disturbed zone boundary.

Drilling activities. Boreholes and their seals are excluded from the definition of the disturbed zone boundary. Therefore, these activities will not affect the definition of the disturbed zone boundary.

Exploratory shaft construction. Shafts are excluded from the definition of the disturbed-zone boundary. Therefore, construction of the exploratory shafts will not affect the definition of the disturbed zone boundary.

Underground construction of ESF drifts and test alcoves. The upper demonstration breakout room is planned to be excavated at a depth of approximately 175 m, which is over 130 m above the main test level. The effects of excavating the room on site conditions are expected to be limited to less than 10 m from the room. Because of the large distance to the main test level and future waste emplacement drifts, construction activities in the upper demonstration breakout room are judged not to significantly affect the definition of the disturbed-zone boundary.

The main test level of the ESF will be constructed at approximately the same elevation as the proposed repository. The effects of constructing drifts and testing alcoves within the ESF main test level on site conditions are expected to be limited to approximately 10 m. This is the same distance that has been preliminarily adopted as the distance to the disturbed zone boundary. Construction of the ESF at the main test level is therefore judged not to affect the definition of the disturbed zone boundary.

ESF testing activities. As described previously, the upper demonstration breakout room is planned to be excavated over 130 m above the main test level. The effects of testing within the room on site conditions are expected to be limited to approximately 10 m. Because of the large distance to the main test level and future waste emplacement drifts, testing activities in the upper demonstration breakout room are judged not to significantly affect the definition of the disturbed zone boundary.

The main test level of the ESF will be constructed at approximately the same elevation as the proposed repository. The effects from testing within the ESF main test level on site conditions are expected to be limited to approximately 10 m. This is the same distance that has been preliminarily adopted as the distance to the disturbed zone boundary. Localized effects within a small volume of rock at distances of greater than 10 m might occur, primarily from water movement through fractures. The summary of effects of water movement in fractures indicates that the changes to matrix saturation will be extremely small. Langkopf (1987) considered the effects of small changes to saturation on ground-water travel time and determined that the effects would not likely be significant. These small changes will therefore not alter the definition of the disturbed-zone boundary. The effects of testing within the ESF main test level are therefore judged not to affect the definition of the disturbed zone boundary.

The potential impacts from creating new paths for likely radionuclide travel and increasing ground-water velocity along paths of likely radionuclide travel are discussed in Section 8.4.3.3.1 (impacts on total-system releases).

The effects of site characterization activities on the pre-waste-emplacement ground-water travel time performance objective are judged not to be significant because the activities are not expected to alter the definition of the boundary of the disturbed zone. According to the intent of the regulation governing GWTT, and subsequent interpretations by NRC position papers, the only way this performance objective can be affected by site characterization activities would be by affecting this boundary. Evaluations of the effects from the various categories of activities indicate that the definitions of the boundary would not be affected.

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*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

*Volume VIII, Part B*

*Chapter 8, Section 8.5, Milestones, Decision Points and Schedule*

*December 1988*


*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

# 8.5 MILESTONES, DECISION POINTS, AND SCHEDULE

This section presents the major milestones, decision points, and summary schedule information established for the site characterization program for the Yucca Mountain site through the submittal of the license application to the Nuclear Regulatory Commission (NRC). The overall schedule information presented in this section is consistent with the Draft Mission Plan Amendment (DOE, 1988a). This information represents a summary of the schedule information provided in Section 8.3, which includes the sequencing, interrelationships, and durations of the studies and activities described in each site investigation and performance assessment or design information need. Schedule information is presented in calendar years.

Section 8.5.1 presents summary schedule information related to the site programs described in Section 8.3.1. An exploratory shaft schedule showing the durations and sequencing of construction- and testing-related activities is included, as well as a schedule for surface-based drilling and testing. Section 8.5.2 presents summary schedule, information for preclosure and postclosure performance assessment issues. Summary schedule information for both preclosure and postclosure repository design issues and for the seal design issue are presented in Section 8.5.3. Section 8.5.4 presents summary schedule information associated with waste package design issues while Section 8.5.5 provides a list of the major decision points and presents a simplified flow diagram showing the interfaces among these decision points. Section 8.5.6 presents a summary schedule for the program elements covered in Sections 8.5.1 through 8.5.4.

The points shown on the summary schedules presented in Sections 8.5.1 through 8.5.4 represent major events or important summary milestones associated with the investigations or information needs presented in Section 8.3. The summary schedule in Section 8.5.6 presents major integration products from the activities presented in Sections 8.5.1 through 8.5.4. Regulatory and institutional milestones have been added, as appropriate, to augment the schedule.

The information provided in this section should be viewed as a snapshot in time with regard to planned site characterization activities and the schedule for those activities. Schedules will be reevaluated and updated as the site characterization program proceeds. Schedule changes will be reported, as appropriate, in semiannual progress reports.

## 8.5.1 SITE CHARACTERIZATION ACTIVITIES AND MILESTONES

The site programs described in Section 8.3.1 do not directly tie to regulatory requirements in the same manner as do the performance and design issues. Instead, site programs have been structured to address acquisition of data on present and expected site characteristics, processes, and events needed to develop site descriptions and to support the resolution of design and performance issues. The performance and design issues were derived from the regulations, thus providing an indirect tie from the site programs to the regulations. The issue resolution strategies discussed in Sections 8.3.2 through 8.3.5 identified the site data required to support the resolution of

the design and performance issues that are tied directly to the NRC (10 CFR Part 60) and other regulatory requirements. This includes data required to support an evaluation of the DOE general siting guidelines (10 CFR Part 960). On the basis of these strategies, the site testing program has been designed to obtain sufficient data to satisfy these requirements.

The following section, 8.5.1.1, provides summary schedule information associated with the site program. A schedule showing the durations and sequencing of major exploratory shaft construction- and testing-related activities is provided in Section 8.5.1.2. Section 8.5.1.3 presents the surface-based drilling and testing schedule. Site characterization study plans are listed in Section 8.5.1.4. Study plans will contain schedule information to supplement that presented in the SCP.

### 8.5.1.1 Site programs

Summary schedule information for those site programs containing one or more investigations described in Section 8.3.1 is provided in this section. The schedule information presented in the figures that follow has been grouped by site program as follows:

1. Geohydrology (8.3.1.2).
2. Geochemistry (8.3.1.3).
3. Rock characteristics (8.3.1.4).
4. Climate (8.3.1.5).
5. Erosion (8.3.1.6).
6. Postclosure tectonics (8.3.1.8).
7. Human interference (8.3.1.9).
8. Meteorology (8.3.1.12).
9. Offsite installations and operations (8.3.1.13).
10. Surface characteristics (8.3.1.14).
11. Thermal and mechanical rock properties (8.3.1.15).
12. Preclosure hydrology (8.3.1.16).
13. Preclosure tectonics (8.3.1.17).

Each investigation within the site program is represented on the summary schedule. The investigation number and brief description are shown as well as major events associated with each investigation. A major event for purposes of these schedules may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. It should be noted that preliminary data meeting applicable quality assurance requirements (Section 8.6) will be available before report availability. Solid lines on the schedules represent investigation durations and dashed lines show interfaces among investigations, as well as data transferred into or out of the site program. The schedules assume continuous integration among activities with only major ties shown. It should also be noted that final reporting may continue into the confirmatory test phase. Candidates for confirmatory testing that have already been identified are shown on the schedules. The rationale for tests continuing as performance confirmation is provided in Section 8.3.5.16.

Geohydrology program (Section 8.3.1.2)

Summary schedule information for the geohydrology program is presented in Figure 8.5-1. The results of studies in this program will be used in the resolution of Issues 1.1 and 1.6 (total system performance and pre-waste-emplacement ground-water travel time, respectively). The activities in this investigation will proceed in parallel with the activities necessary to resolve performance and design issues.

The major events shown on the schedule in Figure 8.5-1 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to DOE on the conceptual model of the saturated zone at Yucca Mountain | 8/90 |
| B | Draft report available to DOE on the evaluation of steep hydraulic gradients near Yucca Mountain | 8/92 |
| C | Draft report available to DOE on regional potentiometric level | 3/93 |
| D | Draft report available to DOE on ground-water discharge in the Amargosa Desert | 6/93 |
| E | Report available to DOE on the estimate of ground-water recharge at Fortymile Wash | 2/94 |
| F | Complete three-dimensional porous equivalent flow model of the saturated zone at Yucca Mountain | 10/94 |
| G | Draft report available to DOE on the preliminary evaluation of unsaturated-zone modeling | 5/90 |
| H | Draft of preliminary report on gaseous-phase flow through the unsaturated zone at Yucca Mountain available to DOE | 10/91 |
| I | Draft report available to DOE on the summary of unsaturated-zone hydrologic modeling | 2/92 |

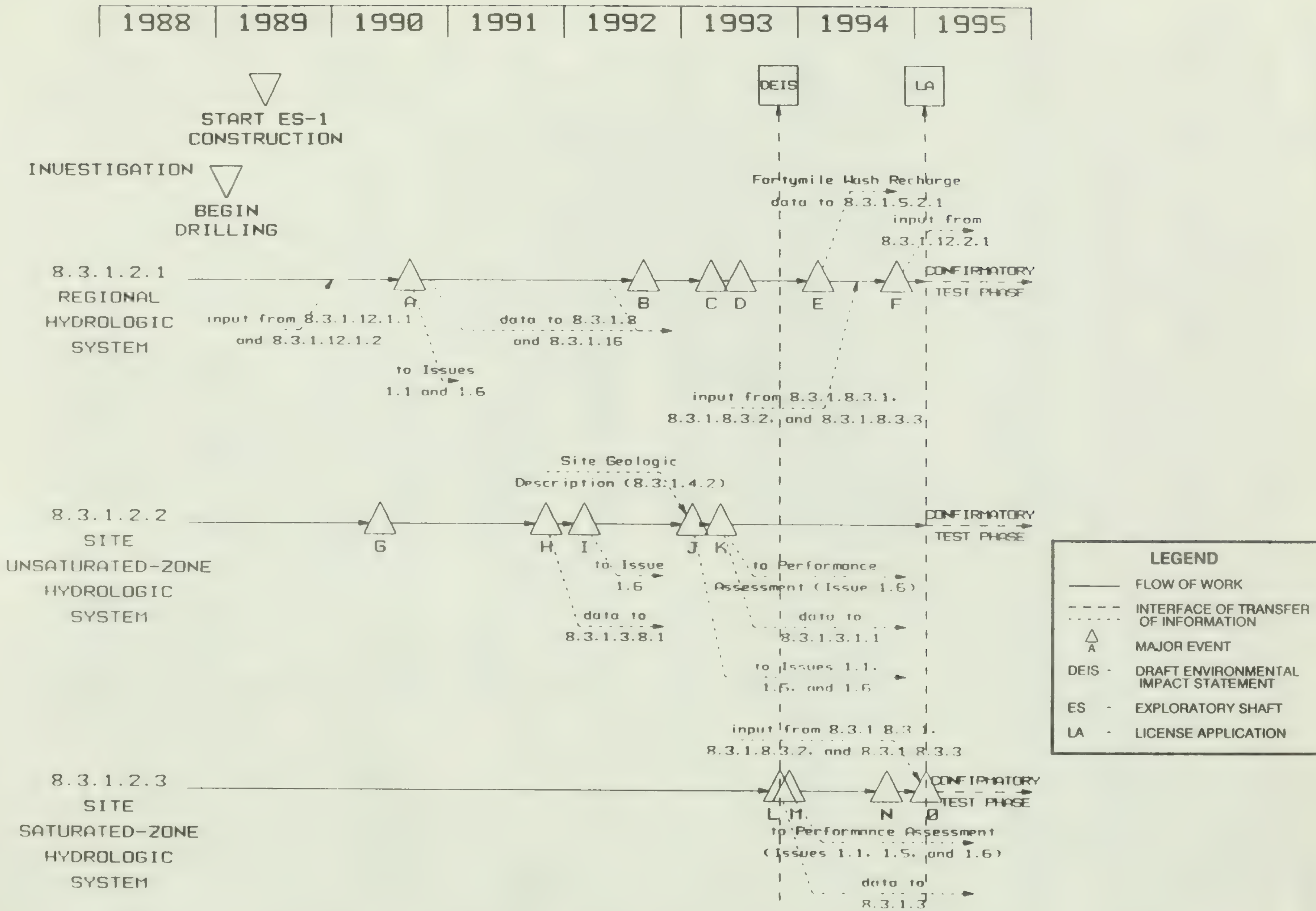


**Figure 8.5-1.** Summary schedule information for the geohydrology program. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Major event | Event description | Date |
|---|---|---|
| J | Draft report available to DOE on the preliminary evaluation of unsaturated-zone hydrology | 1/93 |
| K | Draft report available to DOE on the preliminary evaluation of unsaturated-zone hydrochemistry | 4/93 |
| L | Draft report available to DOE on the hydrochemical characterization of the upper part of the saturated zone within the site area | 10/93 |
| M | Report available to DOE on the preliminary description of the saturated zone | 11/93 |
| N | Report available to DOE on application of fracture network models for the saturated zone to UE25c tests | 9/94 |
| O | Complete conceptual model of the saturated zone | 1/95 |

Geochemistry program (Section 8.3.1.3)

Summary schedule information for the geochemistry program is presented in Figure 8.5-2. The results of studies in this program will be used in the resolution of Issue 1.1 (total system performance). The geochemical retardation that can be relied upon in the rock units between the repository and the accessible environment is one component of the strategy for meeting the release limits specified in the regulations. The activities in this investigation will proceed in parallel with activities supporting resolution of the performance and design issues.

The major events shown on the schedule in Figure 8.5-2 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Interim report on modeling of water chemistry of the saturated zone available to DOE | 12/91 |
| B | Report available to DOE on modeling of unsaturated-zone water chemistry | 7/94 |

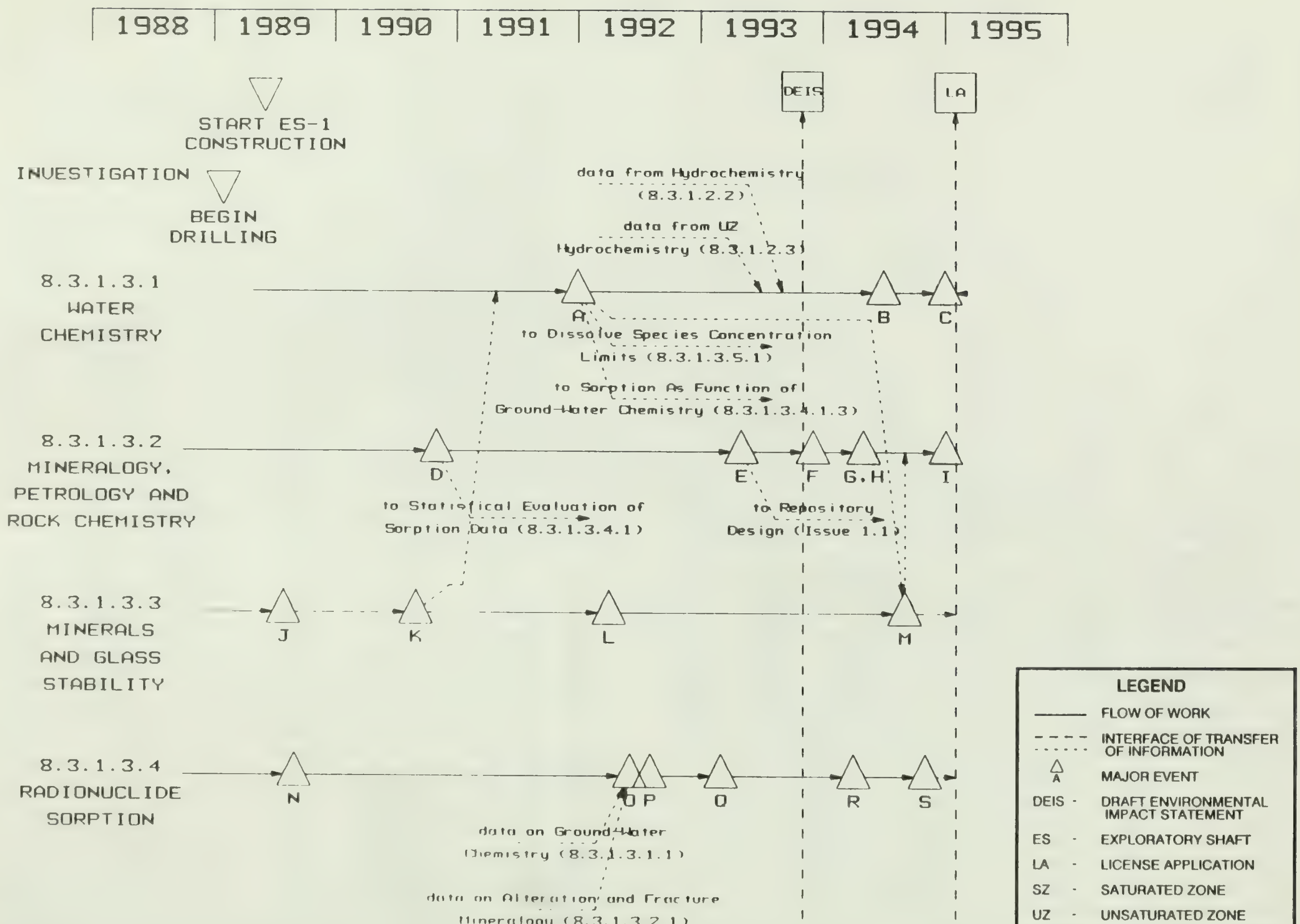


**Figure 8.5-2.** Summary schedule information for the geochemistry program. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 2)

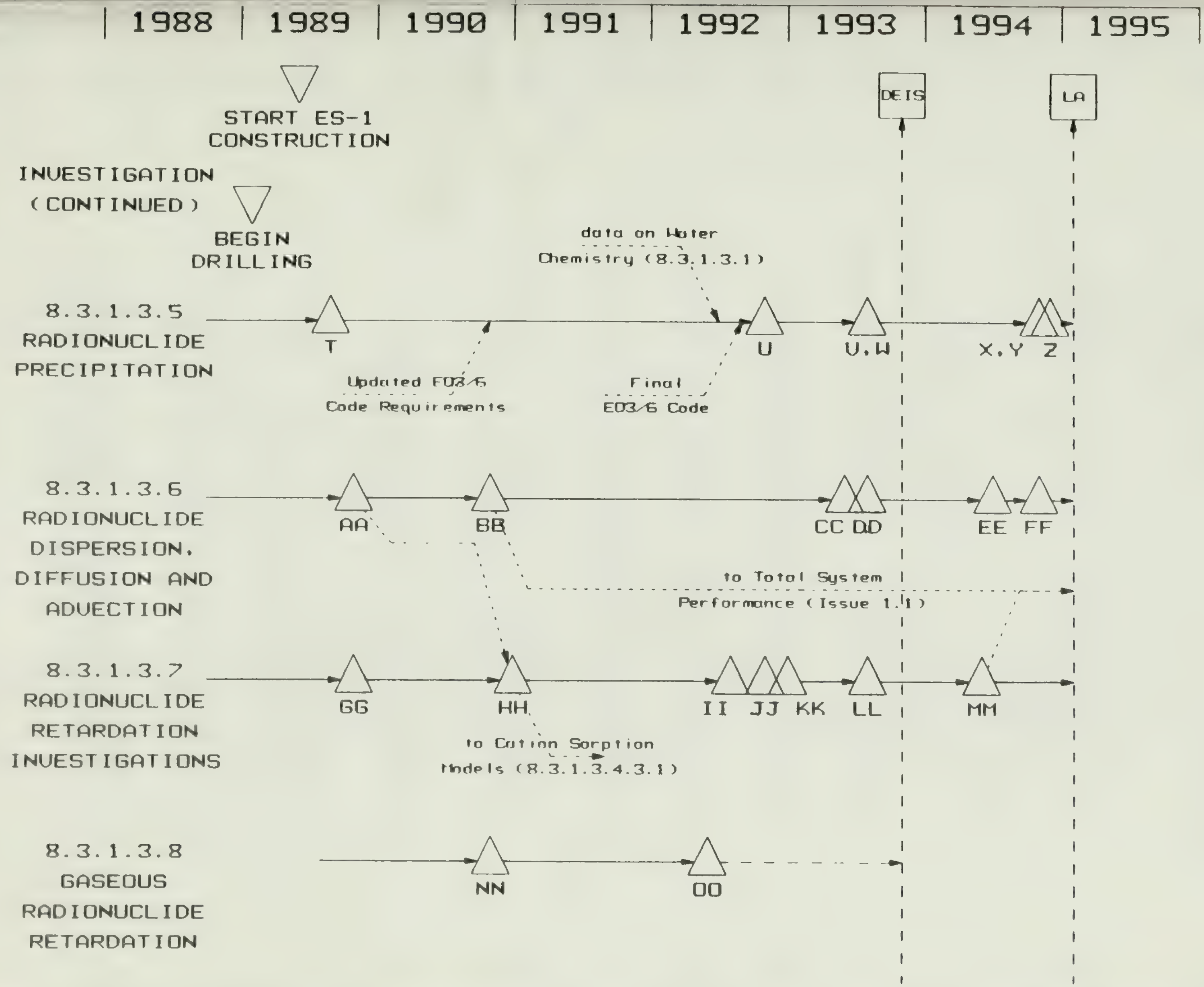


**Figure 8.5-2.** Summary schedule information for the geochemistry program This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 2 of 2)

| Major event | Event description | Date |
|---|---|---|
| C | Report on modeling of ground-water geochemistry available to DOE; report feeds final ground-water chemistry model | 12/94 |
| D | Complete analysis of alteration history of surface fracture deposits; draft report available to DOE on alteration and fracture mineralogy | 9/90 |
| E | Draft report available to DOE on the petrographic stratigraphy and lateral variation within the Topopah Spring Member | 4/93 |
| F | Complete fracture mineralogy model development | 11/93 |
| G | Final report on the history of chemical alteration at Yucca Mountain available to DOE | 4/94 |
| H | Complete three-dimensional pathways model | 4/94 |
| I | Final report on the rating of alternative models for three-dimensional mineralogy available to DOE | 12/94 |
| J | Complete model for analcime thermodynamics | 8/89 |
| K | Draft report available to DOE on natural analogs | 8/90 |
| L | Draft report available to DOE on the kinetics of cristobalite/quartz transition as a function of pH | 2/92 |
| M | Report available to DOE on the conceptual model of mineral evolution | 8/94 |
| N | Draft report available to DOE on sorption measurements with known oxidation states of plutonium | 8/89 |
| O | Draft of final report on microbiological activity and its influence on sorption available to DOE; report feeds final sorption report | 4/92 |
| P | Draft of final report on actinide batch sorption available to DOE | 6/92 |

| Major event | Event description | Date |
|---|---|---|
| Q | Draft of final report on sorption modeling available to DOE; report feeds final sorption report | 1/93 |
| R | Final report on the effects of ground-water composition on sorption available to DOE; report feeds final sorption report | 2/94 |
| S | Final report on sorption isotherms (deconvolution) available to DOE; report feeds final sorption report | 10/94 |
| T | Draft of final report on measured solubilities of Pu, Am, and Np in typical ground-water at Yucca Mountain available to DOE | 8/89 |
| U | Final report on Pu(IV) colloid available to DOE | 9/92 |
| V | Draft report on EQ3/6 database of solubility measurements available to DOE | 7/93 |
| W | Draft report on solubility measurements available to DOE; begin final report on solubility | 7/93 |
| X | Report on the results of speciation measurements available to DOE; report feeds final report on solubility | 9/94 |
| Y | Complete solubility calculations for elements on the EPA critical list; data feeds final report on solubility | 9/94 |
| Z | Final report on colloid formation and stability of Np, Pu, and Am available to DOE; input to final report on solubility | 9/94 |
| AA | Preliminary report on retardation by diffusion in saturated tuff slab available to DOE | 9/89 |
| BB | Draft report on the transport of radionuclides by fracture flow under saturated conditions available to DOE | 9/90 |

| Major event | Event description | Date |
|---|---|---|
| CC | Draft of summary report on the kinetics of sorption available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes | 4/93 |
| DD | Draft reports available to DOE on the results of fractured tuff column experiments and on unsaturated flow column experiments; reports feeds summary report on retardation by diffusion, dispersion, and advective processes | 6/93 |
| EE | Summary report on filtration of radionuclides available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes | 6/94 |
| FF | Final report on retardation by diffusion available to DOE; report feeds summary report on retardation by diffusion, dispersion, and advective processes | 9/94 |
| GG | Draft report available to DOE on the evaluation and recommendation for field tests, laboratory block tests, Caisson tests, natural analog work, and Nevada Test Site nuclide migration work | 9/89 |
| HH | Draft report available to DOE on the results of the retardation sensitivity analysis | 10/90 |
| II | Final field test results available to DOE | 6/92 |
| JJ | Draft of final report on coupled phenomena available to DOE | 9/92 |
| KK | Draft of final report on the geochemical transport code available to DOE | 11/92 |
| LL | Complete revised integrated transport calculations; begin final validation of transport models | 6/93 |

| Major event | Event description | Date |
|---|---|---|
| MM | Final report on the results of retardation sensitivity analysis available to DOE; report feeds final geochemical/geophysical model and report on effectiveness of geochemical barrier | 4/94 |
| NN | Draft report on results of the calculated gas transport rate assessment available to DOE | 9/90 |
| OO | Draft report available to DOE on the results of experimental measurements of gaseous transport rates and retardation rates | 3/92 |

Rock characteristics program (Section 8.3.1.4)

Summary schedule information for the rock characteristics program is presented in Figure 8.5-3. The results of studies in this program will be used to develop an integrated drilling program for the Yucca Mountain site, to better define the geologic framework of the site, and to produce a three-dimensional rock characteristics model for the site. This information will be useful in the resolution of a number of performance and design issues, including Issues 1.1 (total system performance), 1.6 (pre-waste-emplacement ground-water travel time), and 1.11 (configuration of underground facilities).

The major events shown on the schedule in Figure 8.5-3 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to DOE on the preliminary site geologic description | 8/92 |
| B | Complete compilation of structural and stratigraphic information from geologic drillholes | 12/92 |
| C | Draft of report on preliminary geophysics available to DOE; continue surface-based and borehole geophysical surveys and petrophysical properties testing | 7/93 |

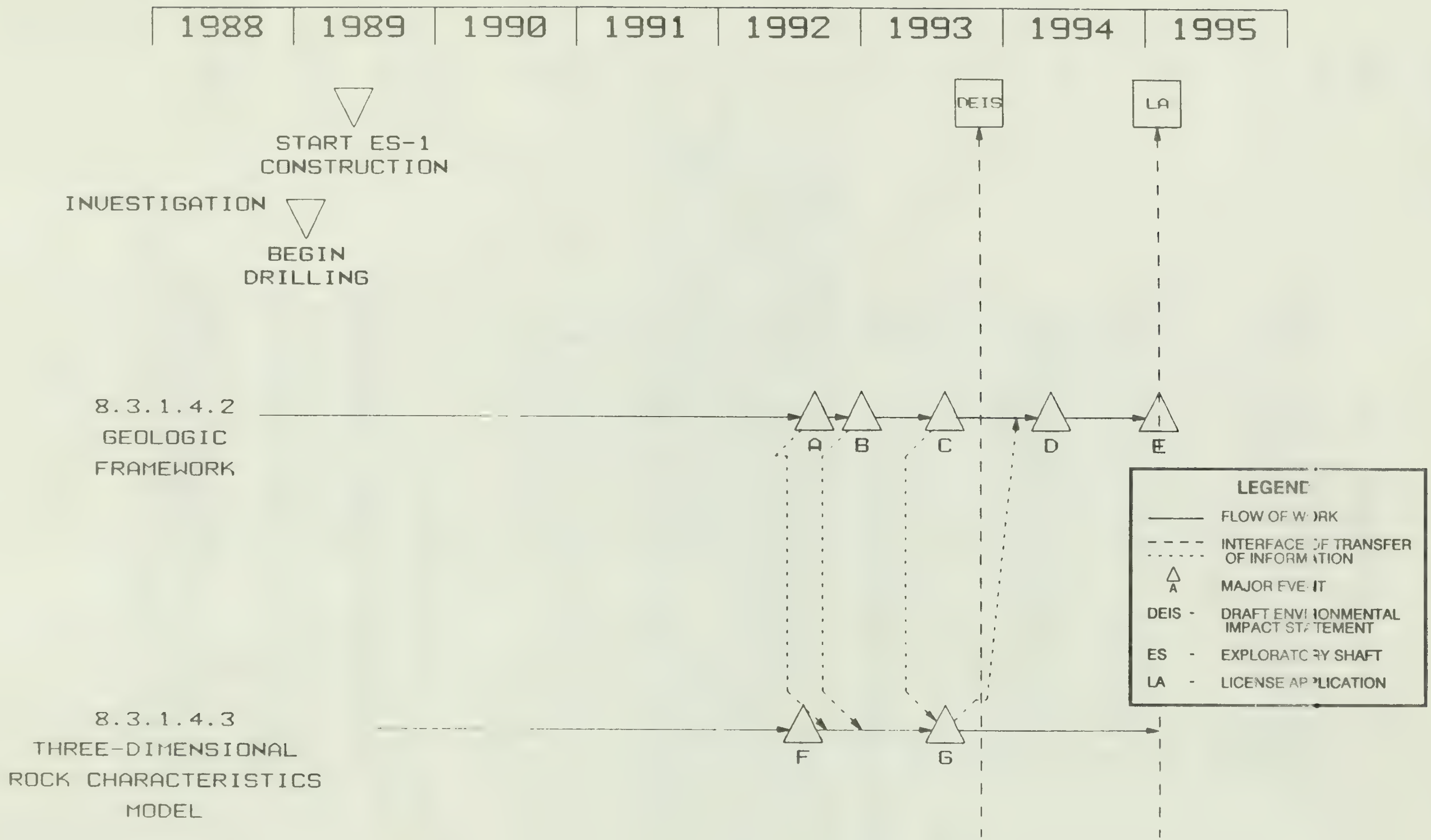


**Figure 8.5-3.** Summary schedule information for the rock characteristics program This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| D | Complete collection of test data for characterization of structural features | 4/94 |
| E | Begin preparation of the final report on borehole evaluation of faults and fractures | 1/95 |
| F | Complete performance assessment-based systematic drilling program | 7/92 |
| G | Reference model for three-dimensional rock characteristics available to DOE; model feeds final three-dimensional model | 7/93 |

Climate program (Section 8.3.1.5)

Summary schedule information for the climate program is presented in Figure 8.5-4. The results of studies in this program will be used to support the resolution of Issue 1.1 (total system performance). Potential changes in climatic conditions will be considered in the evaluation of the cumulative radionuclide release over the next 10,000 yr.

The major events shown on the schedule in Figure 8.5-4 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Final surface deposits map of the Yucca Mountain region available to DOE | 5/91 |
| B | Draft of final report on the eolian history of Yucca Mountain available to DOE | 5/91 |
| C | Draft report on the simulation of future climates available to DOE | 11/92 |
| D | Draft report available to DOE on characterization of the present regional climate and environment | 3/93 |

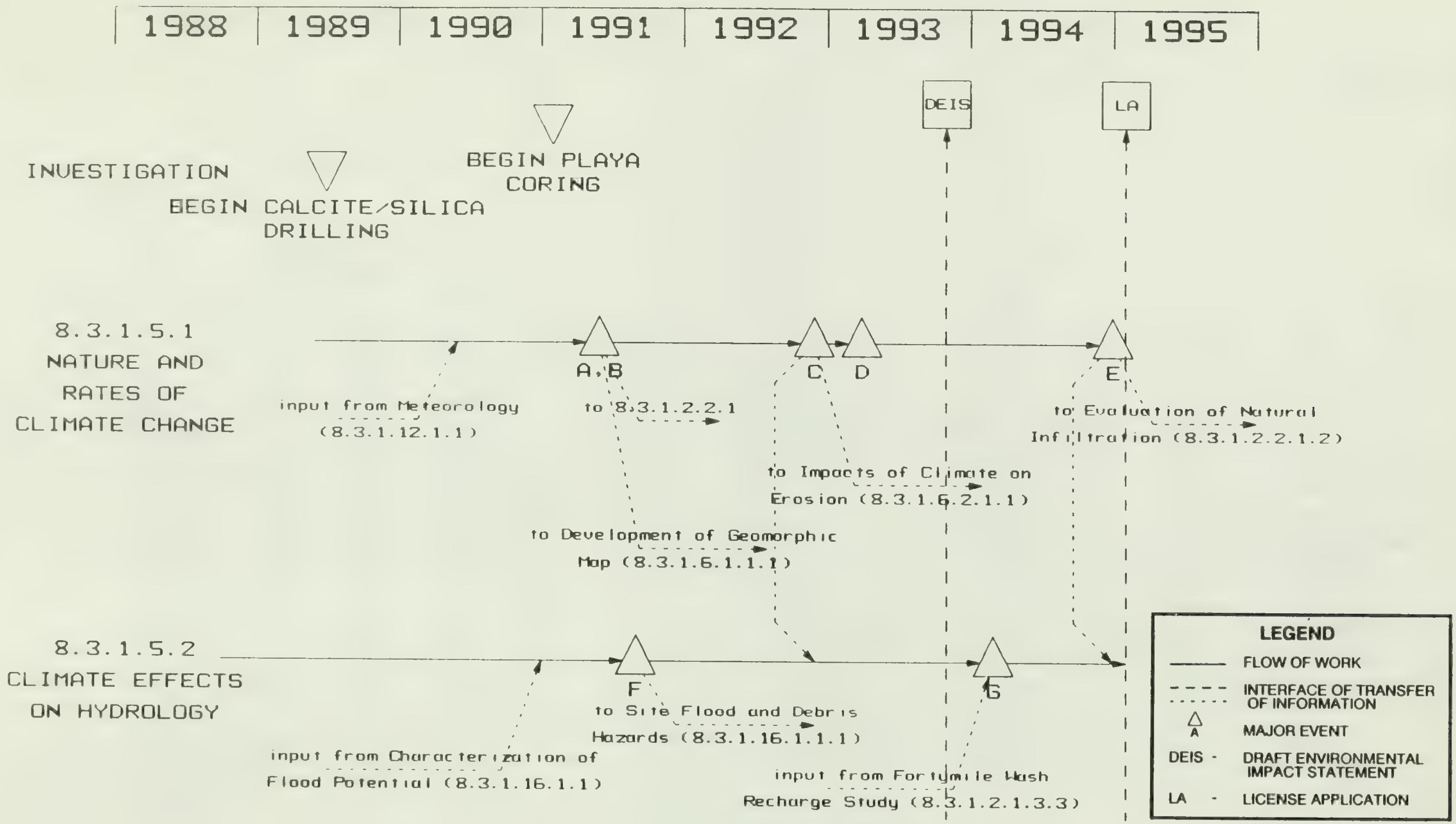


**Figure 8.5-4.** Summary schedule information for the climate program. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Major event | Event description | Date |
|---|---|---|
| E | Report on the Quaternary climate of Yucca Mountain available to DOE | 12/94 |
| F | Draft report summarizing modern flooding events available to DOE; report feeds to report on prediction of future flooding and debris movement | 8/91 |
| G | Final report on the evaluation of past discharge areas available to DOE | 2/94 |

Erosion program (Section 8.3.1.6)

Summary schedule information for the erosion program is presented in Figure 8.5-5. Studies in this program will document the predicted impacts of erosion on the performance of a repository at Yucca Mountain. A series of topical reports are planned to demonstrate that the overall impacts of erosion at the Yucca Mountain site are likely to be insignificant.

The major events shown on the schedule in Figure 8.5-5 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report/map available to DOE on the geomorphology of Yucca Mountain | 8/92 |
| B | Draft report available to DOE on the analysis of hillslope erosion | 8/92 |
| C | Begin studies to evaluate the impacts of future climate on rates of erosion | 7/93 |
| D | Complete evaluation of the impact of future climatic conditions on locations and rates of erosion | 1/95 |
| E | Draft report available to DOE on the impact of future uplift/subsidence and faulting on erosion at Yucca Mountain and vicinity | 8/92 |

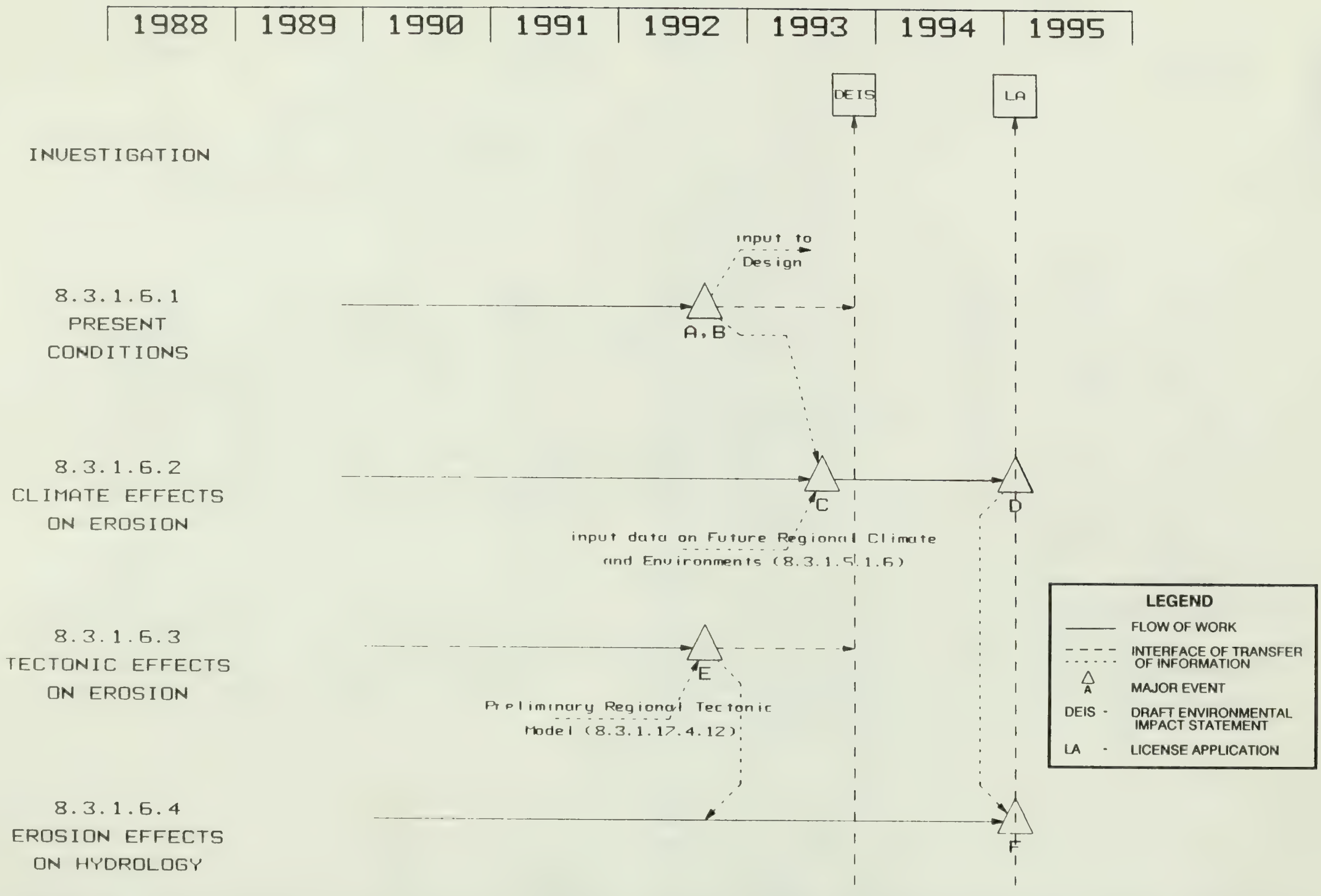


**Figure 8.5-5.** Summary schedule information for the erosion program This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| F | Information on the evaluation of the impact on future climatic conditions on erosion available for studies on the effects of erosion | 1/95 |

Postclosure tectonics program (Section 8.3.1.8)

Summary schedule information for the postclosure tectonics program is presented in Figure 8.5-6. The results of studies in this program will be used to support the resolution of a number of performance and design issues, including Issues 1.1 (total system performance), 1.8 (NRC siting criteria), 1.11 (configuration of underground facilities), and 4.4 (preclosure design and technical feasibility). Scenarios resulting from tectonic processes and events will be considered in the evaluation of the cumulative radionuclide releases over 10,000 yr in Issue 1.1.

The major events shown on the schedule in Figure 8.5-6 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft reports available to DOE on consequences of hydrovolcanic and strombolian eruptions | 9/92 |
| B | Complete preliminary probability estimate of volcanism | 6/93 |
| C | Final report on the probability of future volcanic activity available to DOE | 10/94 |
| D | Complete calculations on the number of waste packages intersected by a fault | 9/90 |
| E | Report on the assessment of waste package rupture due to faulting available to DOE | 12/93 |
| F | Report on faulting, recurrence intervals, and probable cumulative offset in 10,000 yr available to DOE | 6/93 |

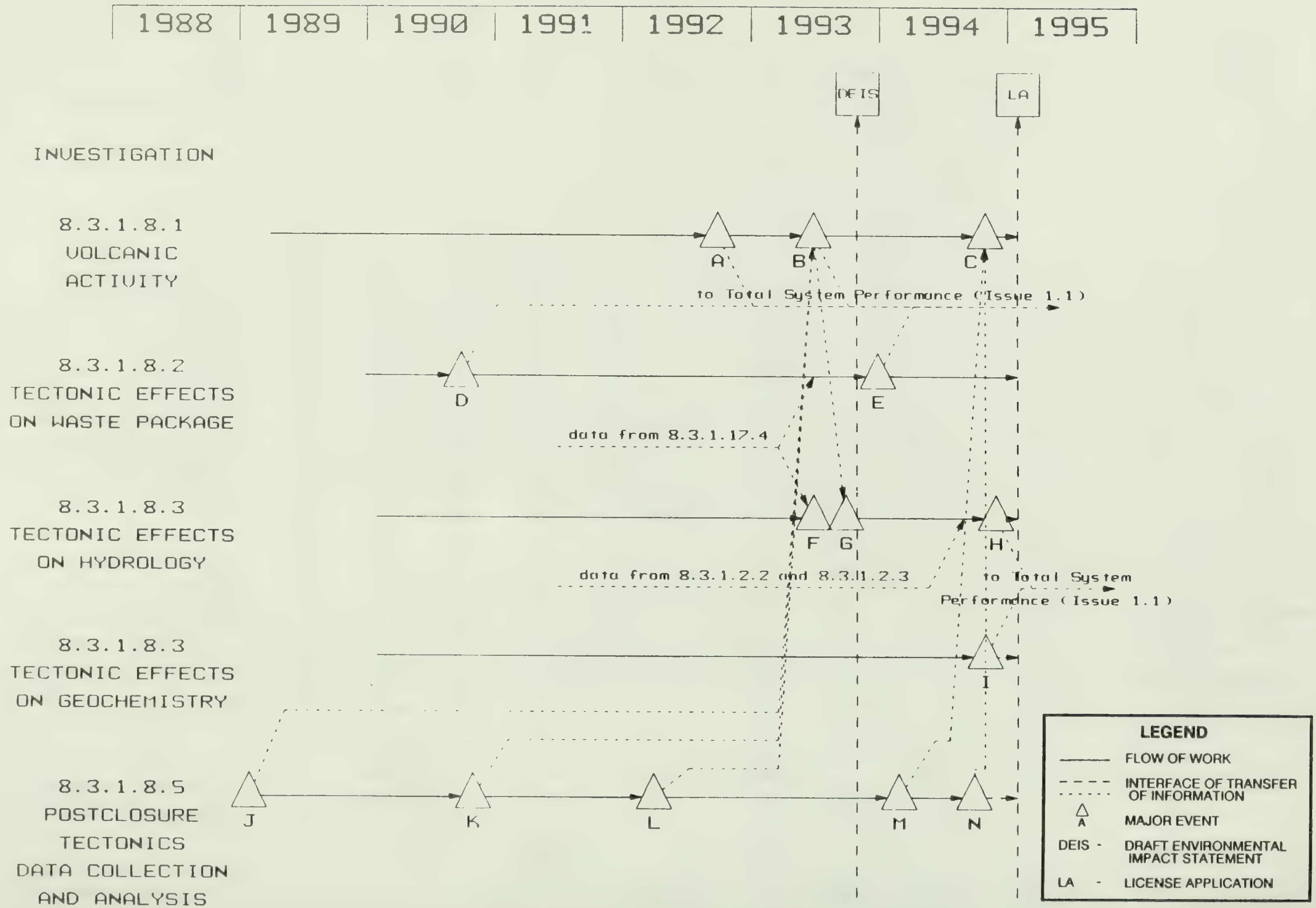


**Figure 8.5-6.** Summary schedule information for the postclosure tectonics program. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Major event | Event description | Date |
|---|---|---|
| G | Report available to DOE on annual probability of volcanic or igneous events in controlled area | 9/93 |
| H | Reports available to DOE on the effects of igneous activity, folding, uplift, subsidence, faulting, and strain changes on average percolation flux, water-table elevation, and hydrologic properties of the rock mass | 11/94 |
| I | Reports available to DOE on the effects of tectonic processes on geochemical changes along faults, mineralogic change due to tectonically induced water-table changes, and fault offset effects on travel pathways | 10/94 |
| J | Report available to DOE on the depth of curie isotherm | 1/89 |
| K | Report available to DOE on the evaluation of heat flow from existing data | 10/90 |
| L | Report available to DOE on age dating of Lathrop Wells, Crater Flats, and Sleeping Butte volcanics | 3/92 |
| M | Report available to DOE on the geology and geochemistry of V-series holes | 2/94 |
| N | Report available to DOE on age dating of V-series holes | 9/94 |

Human interference program (Section 8.3.1.9)

Summary schedule information for the human interference program is presented in Figure 8.5-7. The results of studies in this program will be used to establish that markers and monuments will remain effective for the time specified in the regulations. The likelihood of human interference related to natural resources will be considered in the calculation of total releases to the accessible environment over 10,000 yr as required for the resolution of Issue 1.1 (total system performance).

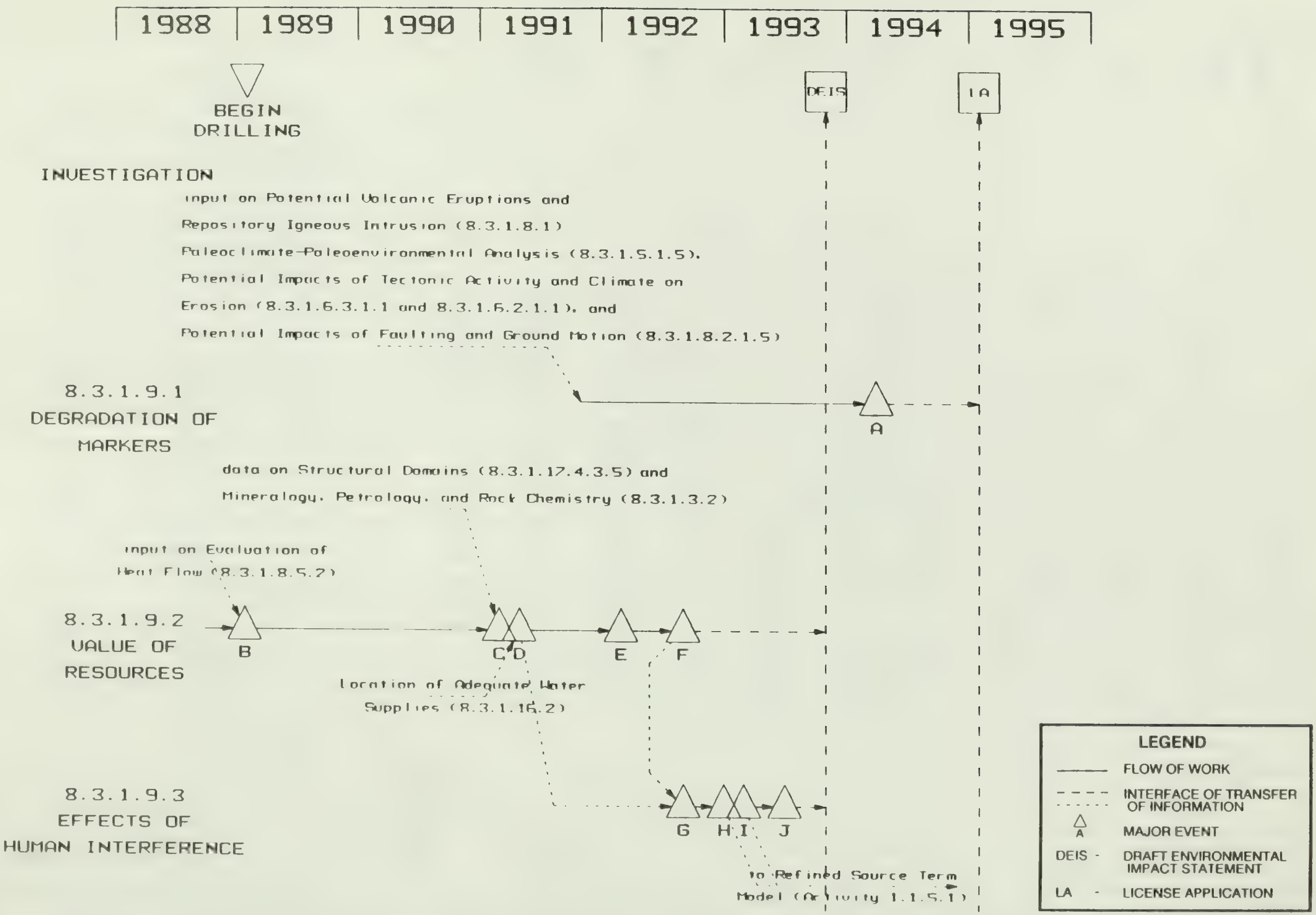


**Figure 8.5-7.** Summary schedule information for the human interference program. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

The major events shown on the schedule in Figure 8.5-7 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Report available to DOE synthesizing data on the natural processes that could affect marker survivability | 3/94 |
| B | Initiate assessment of geothermal energy potential | 5/90 |
| C | Initiate geophysical/geological assessment of mineral resources | 2/91 |
| D | Draft report available to DOE on the assessment of water resources at Yucca Mountain | 4/91 |
| E | Draft report available to DOE on the mineral and energy potential of the site | 2/92 |
| F | Draft of final report on the evaluation of natural resource potential at the site available to DOE | 8/92 |
| G | Initiate work on the determination of factors contributing to the likelihood of human interference and intrusion at Yucca Mountain | 8/92 |
| H | Draft report available to DOE on the potential effects of exploiting ground-water resources proximal to the Yucca Mountain site | 12/92 |
| I | Draft report available to DOE on factors contributing to the likelihood of human interference and intrusion at Yucca Mountain | 2/93 |
| J | Complete assessment of noncredible human interference | 6/93 |

Meteorology program (Section 8.3.1.12)

Summary schedule information for the meteorology program is presented in Figure 8.5-8. The results of studies and monitoring performed in this program will be used to support issue resolution of a number of preclosure issues concerned with radiological safety, including Issues 2.1 (public radiological exposures--normal conditions), 2.2 (worker radiological safety--normal conditions), 2.3 (accidental radiological releases), and 2.7 (repository design criteria for radiological safety). The activities in this program will proceed in parallel with the performance and design activities.

The major events shown on the schedule in Figure 8.5-8 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to DOE on regional meteorological conditions | 1/90 |
| B | Annual meteorological monitoring data reports available to DOE | 6/89<br>8/89<br>4/90<br>4/91<br>4/92 |
| C | Draft of five-year summary report on meteorological conditions available to DOE | 2/93 |
| D | Complete compilation of data on wind flow patterns for use in estimating doses to the public (Issues 2.1 and 2.3) | 2/93 |
| E | Draft report available to DOE on extreme weather phenomena and expected recurrence intervals | 3/91 |

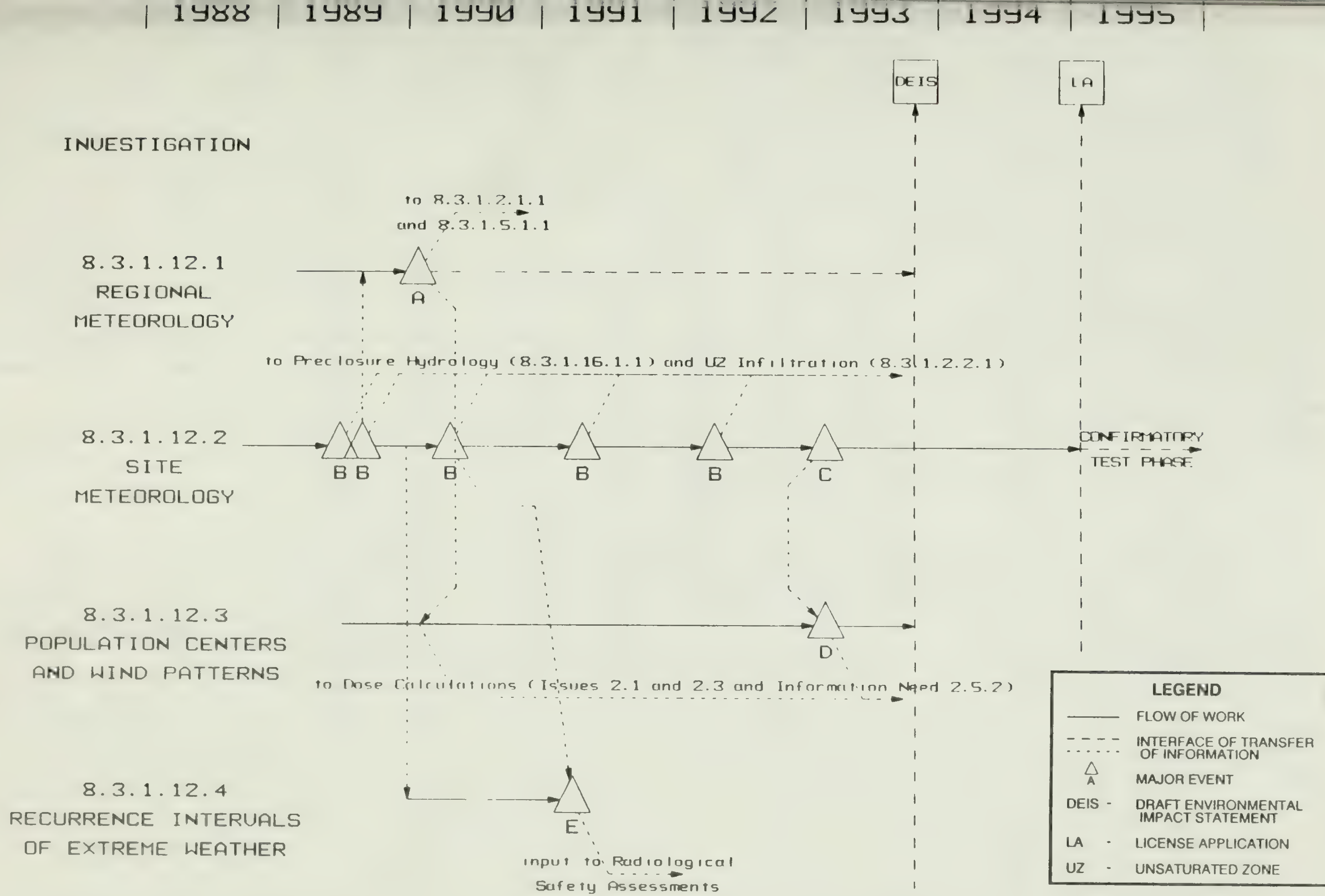


**Figure 8.5-8.** Summary schedule information for the meteorology program This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

Offsite installations and operations program (Section 8.3.1.13)

Summary schedule information for the offsite installations and operations program is presented in Figure 8.5-9. The results of the activities of this program will be used to support the resolution of a number of preclosure issues concerned with radiological safety requirements, including Issues 2.1 (public radiological exposures--normal conditions), 2.2 (worker radiological safety--normal conditions), 2.3 (accidental radiological releases), 2.5 (higher-level findings--preclosure radiological safety), and 2.7 (repository design criteria for radiological safety). The activities in this program will proceed in parallel with the performance and design activities.

The major events shown on the schedule in Figure 8.5-9 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft of environment monitoring report 1988 available to DOE | 5/89 |
| B | Complete survey and evaluation of nuclear fuel cycle activities | 10/89 |
| C | Complete identification of near-site activities (non-nuclear related) | 6/90 |
| D | Complete analysis of overflight hazards due to USAF activities | 9/89 |
| E | Environmental monitoring data summaries available to DOE; environmental monitoring will continue beyond 1995 | 5/90<br>5/91<br>5/92<br>5/93<br>5/94 |
| F | Draft of final report on USAF overflight impacts available to DOE | 3/91 |
| G | Summary report available to DOE documenting environmental and radiological data | 9/92 |

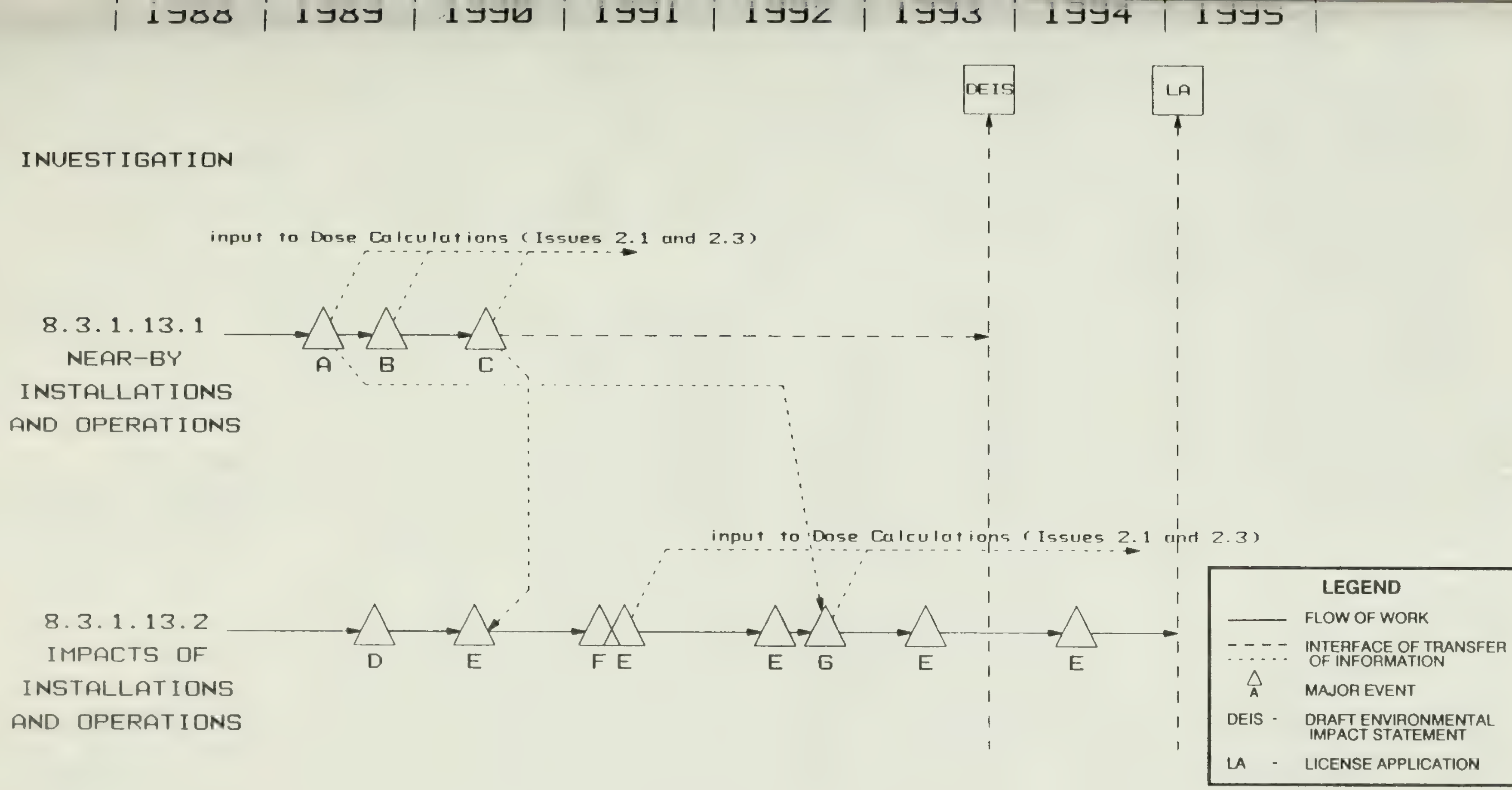


**Figure 8.5-9.** Summary schedule information for the offsite installations and operations program This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

Surface characteristics program (Section 8.3.1.14)

Summary schedule information for the surface characteristics program is presented in Figure 8.5-10. The results of the activities completed for this investigation and the studies in Investigation 8.3.1.14.2 will be used in the design and siting of surface repository facilities at the Yucca Mountain site. The principal issue concerned with surface-facility design is Issue 4.4 (preclosure design and technical feasibility). This program will proceed in parallel with the activities supporting resolution of the performance and design issues.

The major events shown on the schedule in Figure 8.5-10 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to DOE on the results of site reconnaissance; begin preliminary exploration | 5/91 |
| B | Draft of updated reports on physical properties and index laboratory testing and mechanical and dynamic laboratory properties testing available to DOE | 8/91 |
| C | Draft of updated reports on the results of physical and mechanical property field tests and geophysical field measurements available to DOE | 8/91 |
| D | Draft report available to DOE on the results of detailed exploration | 6/93 |

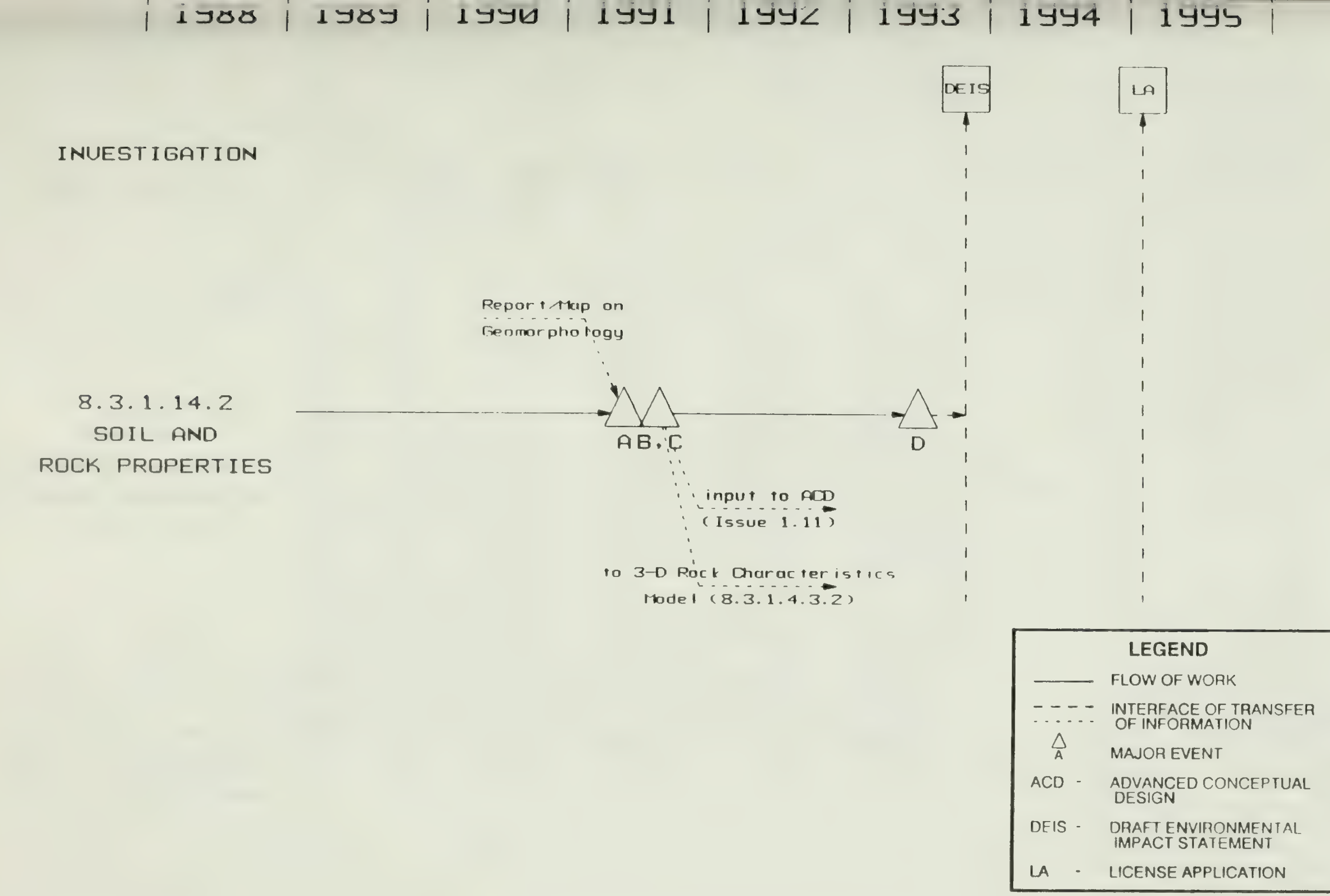


**Figure 8.5-10.** Summary schedule information for the surface characteristics program This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

Thermal and mechanical rock properties program (Section 8.3.1.15)

Summary schedule information for the thermal and mechanical rock properties program is presented in Figure 8.5-11. The results of studies in this program will be used in the design of the underground repository facilities. Issue 1.11 (configuration of underground facilities) will use the stratigraphic data, the information on geologic structure, and information on thermal and mechanical rock properties to develop appropriate layouts for the underground repository facilities.

The major events shown on the schedule in Figure 8.5-11 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft of final report on thermal, mechanical, thermomechanical, and mechanical properties available to DOE | 9/91 |
| B | Draft report available to DOE on the effects of variable environmental conditions on the mechanical properties of fractures | 7/92 |
| C | Draft of final report on the analysis of spatial variation of thermal and mechanical properties of intact rock available to DOE | 5/93 |
| D | Complete rock mechanics data summary | 10/93 |
| E | Draft report available to DOE on site ambient thermal conditions | 1/92 |
| F | Draft of final report on anelastic strain recovery testing available to DOE | 7/92 |
| G | Draft report available to DOE on the results of in situ stress testing | 5/93 |

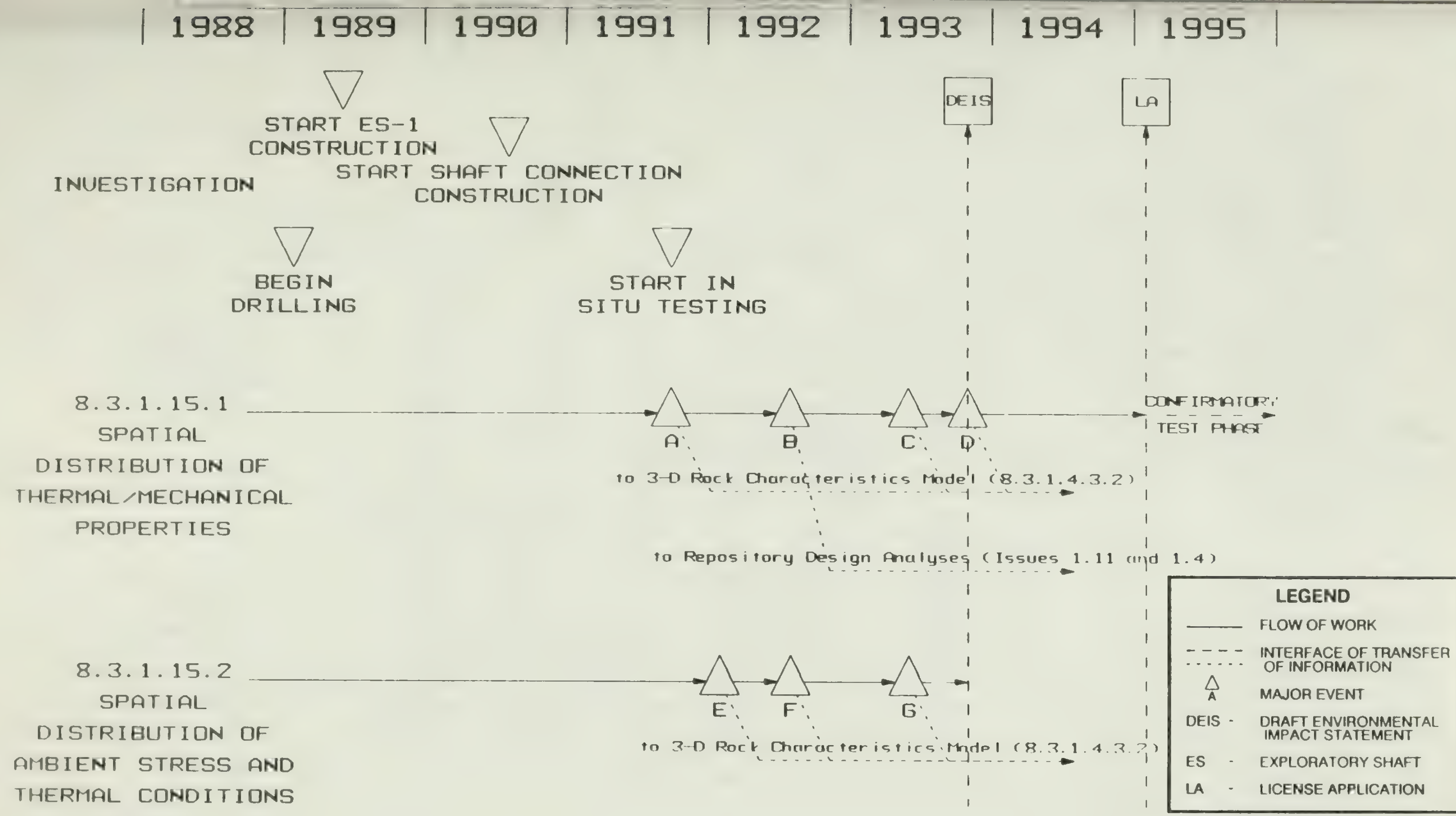


**Figure 8.5-11.** Summary schedule information for the thermal and mechanical rock properties program. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

Preclosure hydrology program (Section 8.3.1.16)

Summary schedule information for the preclosure hydrology program is presented in Figure 8.5-12. The results of studies in this program will be used to support resolution of Issue 4.4 (preclosure design and technical feasibility). Potential flooding hazards will be considered in the design and placement of surface facilities. This program will provide input to the plans being developed for obtaining the water necessary to support repository-related activities.

The major events shown on the schedule in Figure 8.5-12 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft of summary report on prehistoric flooding available to DOE (report associated with Study 8.3.1.5.2.1.1.) | 2/91 |
| B | Compile current information on future flooding and debris transport and begin preparation of final report | 12/94 |
| C | Draft report available to DOE on the assessment of wells J-12 and J-13 for repository water supply | 6/90 |
| D | Draft report available to DOE on repository-related water supply alternatives | 12/91 |
| E | Draft report available to DOE on the effects of water withdrawals on local flow system | 6/92 |
| F | Draft report available to DOE on ground-water conditions within and above potential host rock | 11/92 |

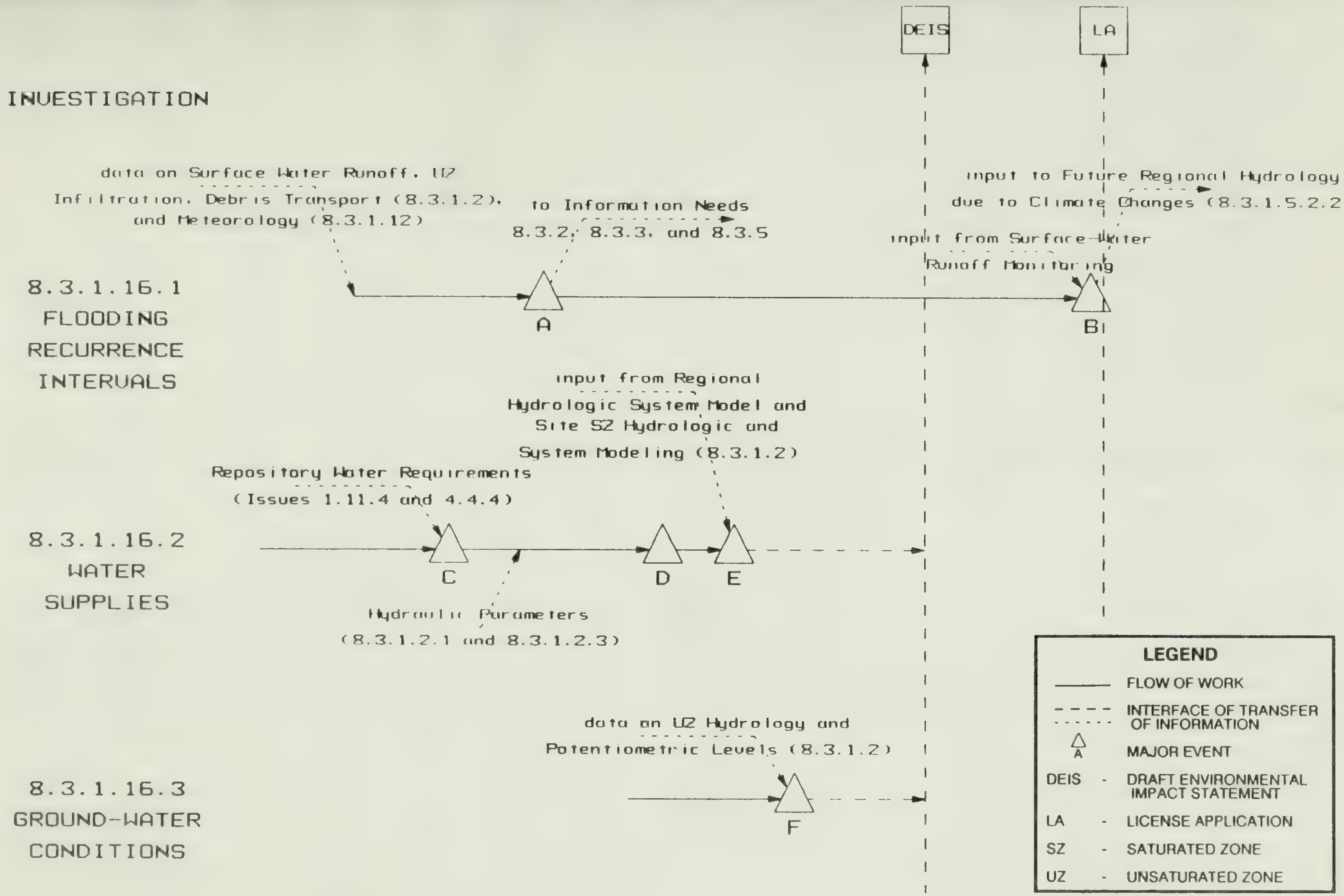


**Figure 8.5-12.** Summary schedule information for the preclosure hydrology program This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

Preclosure tectonics program (Section 8.3.1.17)

Summary schedule information for the preclosure tectonics program is presented in Figure 8.5-13. The results of studies in this program will be used to support the resolution of Issue 4.4 (preclosure design and technical feasibility). Designs of the surface and underground facilities will account for all aspects of the seismic hazards recognized at the Yucca Mountain site. Hazards due to volcanic activity and to both vibratory ground motion and surface faulting will be identified through activities in this program. Repository design activities will proceed in parallel with the studies in this program.

The major events shown on the schedule in Figure 8.5-13 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft reports available on potential ash flow thickness and preclosure hazards of volcanism at the site | 3/90 |
| B | Draft final report on the potential for faulting at the surface facilities available to DOE | 8/92 |
| C | Draft report available to DOE on the potential for displacement on faults that intersect underground facilities | 8/92 |
| D | Draft preliminary report on the probabilistic seismic hazards assessment available to DOE | 8/90 |
| E | Final ground motion and calibrated site effects model selected | 3/92 |
| F | Preliminary deterministic design values available | 8/92 |
| G | Relevant earthquake sources identified and earthquake magnitude estimates completed | 9/92 |
| H | Draft report available to DOE on final ground motion design basis and time histories | 6/93 |
| I | Surface facilities trench logging completed | 12/89 |

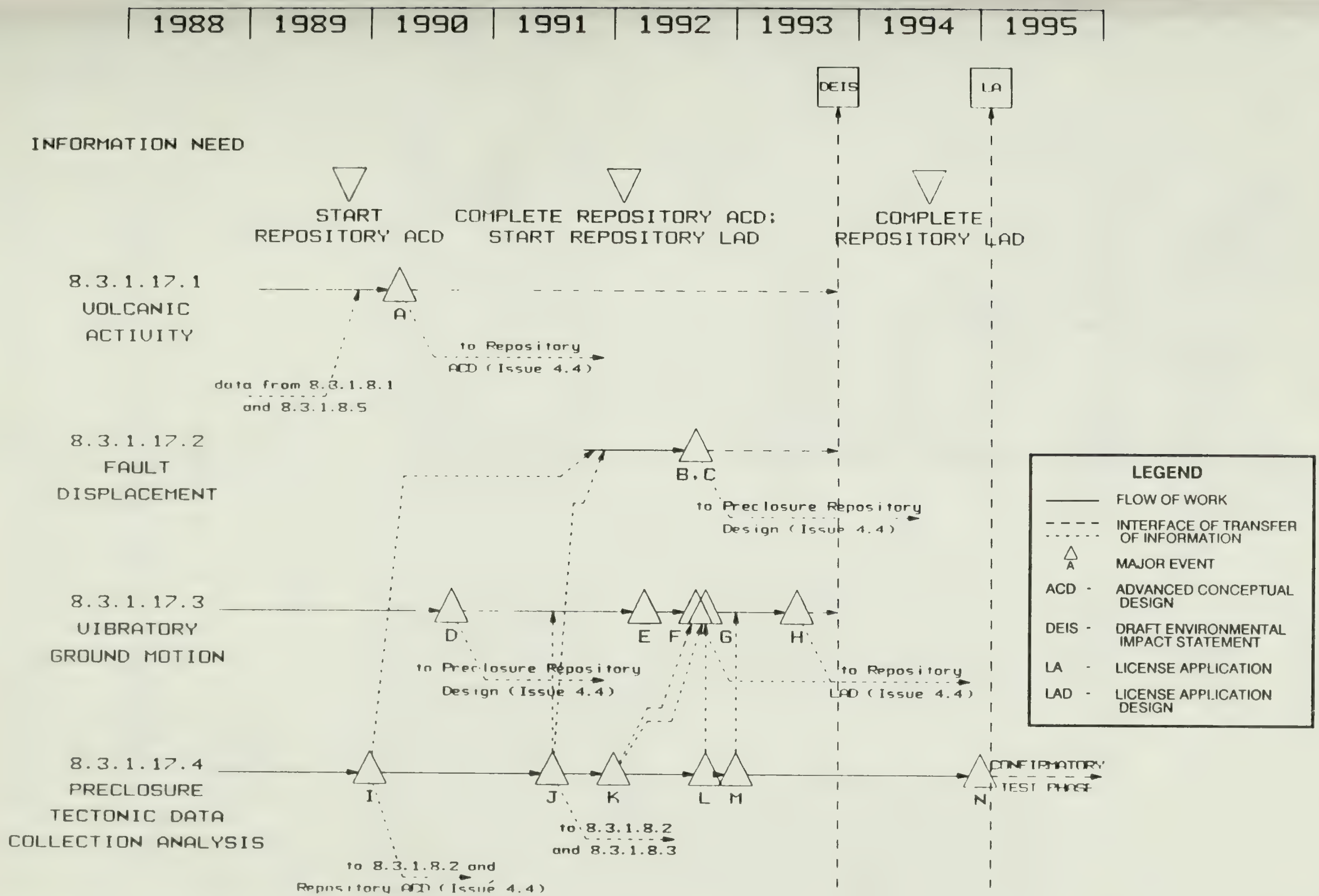


**Figure 8.5-13.** Summary schedule information for the preclosure tectonics program This network is consistent with the Draft Mission Plan Amendment (DOE 1988c) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| J | Complete fault studies on north-trending faults (Bow Ridge, Windy Wash, Fatigue Wash, Paintbrush Canyon, Ghost Dance, Solitario Canyon faults) in the site area | 6/91 |
| K | Report available to DOE on contemporary seismicity studies and strong motion recordings at the site | 12/91 |
| L | Complete evaluation of northeast-trending faults (Mine Mountain, Rock Valley, Stagecoach Road, Cane Springs faults) | 9/92 |
| M | Complete intermediate depth seismic reflections surveys at the site | 12/92 |
| N | Final annual report on seismic data available to DOE; continue seismic network monitoring and Yucca Mountain base station network monitoring (geodetic leveling) as performance conformation | 12/94 |

### 8.5.1.2 Exploratory shaft

The following table presents a list of major milestones related to the construction of, and testing in, the exploratory shaft (ES). A schedule for these activities is presented in Figure 8.5-14. As with the schedules in the site programs, the information provided in this section should be viewed as a snapshot in time with regard to planned ES activities and the schedule for those activities. The schedule has been included to illustrate the sequence of activities planned and the relationships of the various activities to the construction schedule and to each other. It should be recognized that certain in situ tests will be continued for confirmatory purposes after the license application has been submitted.

| Milestone number | Related SCP section | Milestone description | Date |
|---|---|---|---|
| | | CONSTRUCTION-RELATED ACTIVITIES AND MILESTONES | |
| M645 | 8.4.2.3.4 | Start exploratory shaft (ES) site preparation | 12/88 |
| R013 | 8.4.2.3.4.2 | Start construction of surface facilities | 1/89 |

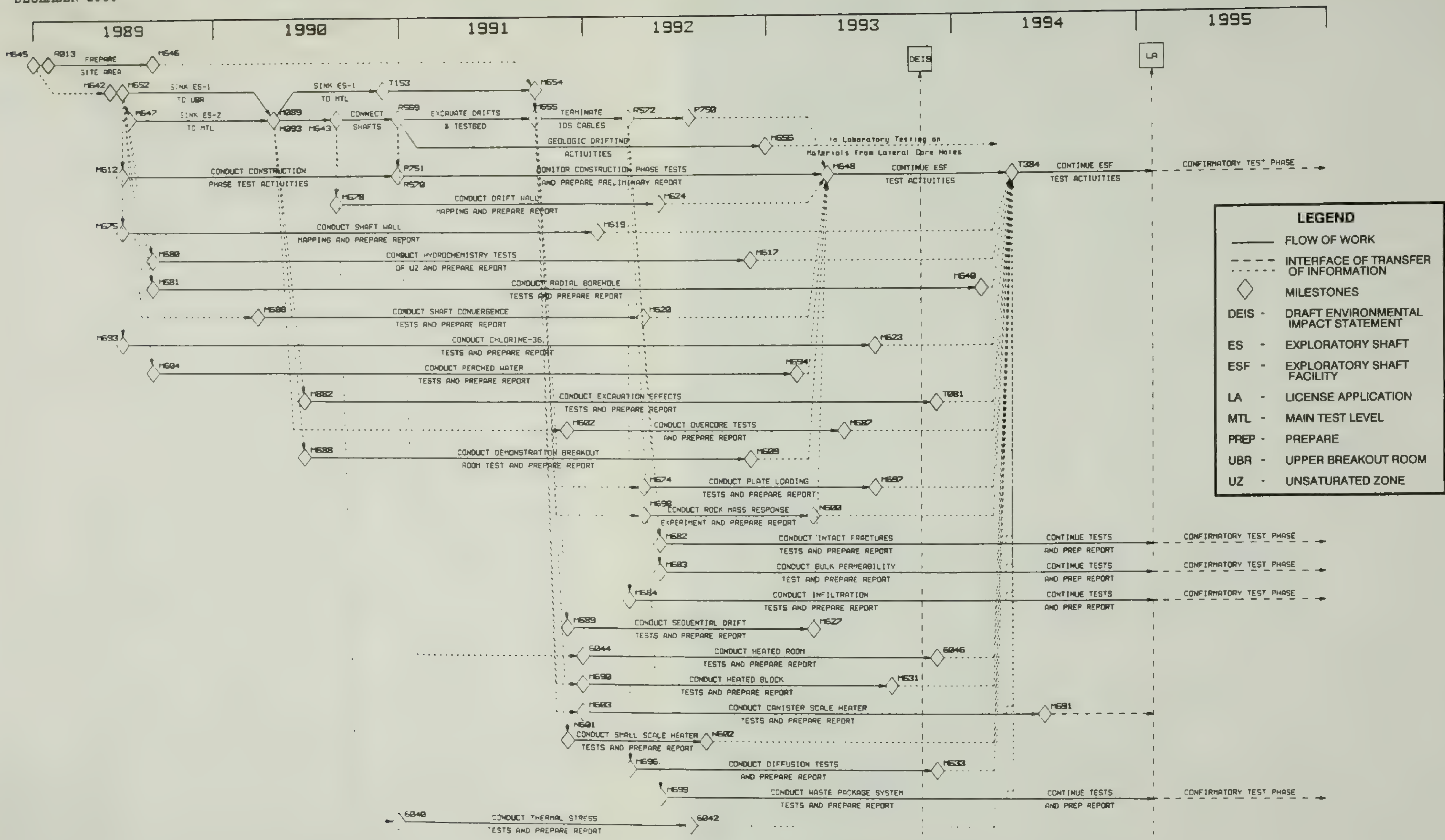


**Figure 8.5-14.** Summary schedule for the exploratory shaft construction and testing. This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Milestone number | Related SCP section | Milestone description | Date |
|---|---|---|---|
| | | CONSTRUCTION-RELATED ACTIVITIES AND MILESTONES (continued) | |
| M642 | NA[a] | Issue revised surface Title II design | 6/89 |
| M652 | 8.4.2.3.4.3 | Start ES-1 shaft construction | 6/89 |
| M647 | 8.4.2.3.4.3 | Start ES-2 shaft construction | 6/89 |
| M646 | 8.4.2.3.4.2 | Complete surface facility construction | 8/89 |
| M089 | 8.4.2.3.4.4 | Complete ES-1 upper break-out room | 4/90 |
| M093 | 8.4.2.3.4.4 | Complete ES-2 main test level breakout room | 4/90 |
| M643 | 8.4.2.3.4.4 | Complete ES-2 shaft construction | 8/90 |
| T153 | 8.4.2.3.4.4 | Complete ES-1 excavation to main test level | 11/90 |
| R569 | 8.4.2.3.4.4 | Complete connection of ES-1 to ES-2 | 12/90 |
| M654 | 8.4.2.3.4.4 | Complete ES-1 shaft liner and internals | 9/91 |
| M655 | 8.4.2.3.4.4 | Complete ES-2 main test level excavation | 9/91 |
| R572 | NA | Test bed cables terminated | 3/92 |
| P750 | NA | Complete exploratory shaft facility Title III design | 7/92 |
| M656 | 8.4.2.3.4.4 | Complete geologic drifting | 12/92 |
| | | TESTING-RELATED ACTIVITIES AND MILESTONES | |
| M612 | NA | Start ES construction phase testing | 6/89 |
| M675 | 8.3.1.4.2.2.4 | Begin shaft wall mapping | 6/89 |
| M693 | 8.3.1.2.2.2.1 | Begin chlorine-36 dating pore water test | 6/89 |
| M604 | 8.3.1.2.2.4.7 | Begin perched-water test | 8/89 |
| M680 | 8.3.1.2.2.4.8 | Begin hydrochemistry tests | 8/89 |
| M681 | 8.3.1.2.2.4.4 | Begin radial borehole tests | 8/89 |

| Milestone number | Related SCP section | Milestone description | Date |
|---|---|---|---|
| | | TEST-RELATED ACTIVITIES AND MILESTONES (continued) | |
| M686 | 8.3.1.15.1.5.1 | Begin shaft convergence test | 3/90 |
| M688 | 8.3.1.15.1.5.2 | Begin demonstration breakout room testing | 6/90 |
| M882 | 8.3.1.2.2.4.5 | Begin excavation effects test | 6/90 |
| M678 | 8.3.1.4.2.2.4 | Begin drift wall mapping | 8/90 |
| P751 | NA | Complete construction phase testing | 12/90 |
| R570 | NA | Start in situ phase testing | 12/90 |
| 6040 | 8.3.1.15.1.6.4 | Begin thermal stress test | 12/90 |
| M602 | 8.3.1.15.2.1.2 | Begin overcore stress experiments | 11/91 |
| M689 | 8.3.1.15.1.5.3 | Begin sequential drift mining evaluations | 11/91 |
| N601 | 8.3.1.15.1.6.1 | Begin heater experiment in unit TSw1 | 11/91 |
| M690 | 8.3.1.15.1.6.3 | Begin Yucca Mountain heated block experiment | 12/91 |
| M603 | 8.3.1.15.1.6.2 | Begin canister-scale heater experiments | 12/91 |
| 6044 | 8.3.1.15.1.6.5 | Begin heated room test | 12/91 |
| M619 | 8.3.1.4.2.2.4 | Complete shaft wall mapping report | 1/92 |
| M696 | 8.3.1.2.2.5.1 | Begin diffusion test | 3/92 |
| M620 | 8.3.1.15.1.5.1 | Complete shaft convergence testing data report | 4/92 |
| M674 | 8.3.1.15.1.7.1 | Begin plate loading tests | 4/92 |
| M698 | 8.3.1.15.1.7.2 | Begin rock mass response experiment | 4/92 |
| M624 | 8.3.1.4.2.2.4 | Complete report on drift wall mapping | 5/92 |
| M682 | 8.3.1.2.2.4.1 | Begin intact-fracture tests | 5/92 |
| M683 | 8.3.1.2.2.4.3 | Begin bulk-permeability tests | 5/92 |

| Milestone number | Related SCP section | Milestone description | Date |
|---|---|---|---|
| TEST-RELATED ACTIVITIES AND MILESTONES (continued) | | | |
| M699 | 8.3.4.2.4.4 | Begin waste package system test | 5/92 |
| M684 | 8.3.1.2.2.4.2 | Begin percolation test | 5/92 |
| 6042 | 8.3.1.15.1.6.4 | Complete report on thermal stress test | 7/92 |
| N602 | 8.3.1.15.1.6.1 | Complete final report on heater experiment in unit TSw1 | 8/92 |
| M609 | 8.3.1.15.1.5.2 | Complete report on demonstration breakout room testing | 11/92 |
| M617 | 8.3.1.2.2.4.8 | Complete final report on the results of hydrochemistry tests | 11/92 |
| M694 | 8.3.1.2.2.4.7 | Complete report on the results of the perched-water test | 2/93 |
| M627 | 8.3.1.15.1.5.3 | Complete sequential drift mining evaluations report | 3/93 |
| N600 | 8.3.1.15.1.7.2 | Complete final report on rock mass response experiment | 3/93 |
| M648 | NA | Provide in situ test data for the draft environmental impact statement (DEIS) | 4/93 |
| M687 | 8.3.1.15.2.1.2 | Complete report on overcore stress experiments | 5/93 |
| M623 | 8.3.1.2.2.2.1 | Complete chlorine-36 analysis report | 7/93 |
| M697 | 8.3.1.15.1.7.1 | Complete final report on plate loading tests | 7/93 |
| M631 | 8.3.1.15.1.6.3 | Complete report on the results of the Yucca Mountain heated block experiment | 8/93 |
| T081 | 8.3.1.2.2.4.5 | Complete report on the results of the excavations effects test | 11/93 |

| Milestone number | Related SCP section | Milestone description | Date |
|---|---|---|---|
| | | TEST-RELATED ACTIVITIES AND MILESTONES (continued) | |
| 6046 | 8.3.1.15.1.6.5 | Complete report on the results of the heated room test | 11/93 |
| M633 | 8.3.1.2.2.5.1 | Complete final report on the results of diffusion tests | 11/93 |
| M640 | 8.3.1.2.2.4.4 | Complete report on the results of the radial borehole tests | 2/94 |
| T384 | NA | Provide in situ test data for the license application (LA) | 4/94 |
| M691 | 8.3.1.15.1.6.2 | Complete report on the results of canister-scale heater experiments | 6/94 |

[a]NA = not applicable

### 8.5.1.3 Surface-based drilling and testing

The schedule for planned surface-based drilling and testing, upon which the site program schedules are based, is summarized in Figure 8.5-15. This figure includes a brief description of planned drilling and testing activities as well as major events associated with each activity. The related SCP section numbers under which these activities are discussed in greater detail are also provided on the figure. Solid lines on the schedule represent activity durations and dashed lines show constraints among drilling and testing activities. The events shown on the schedule and their planned dates of completion are provided in Table 8.5-1.

### 8.5.1.4 Site characterization study plans

Table 8.5-2 provides a list of site characterization study plans that will present details of site-related studies, tests, and analyses and the schedule for those activities as a supplement to the information in this document. Preparation and review of study plans will be staggered depending on when the studies are to commence. The availability of new or updated study plans will be reported in semiannual site characterization progress reports.

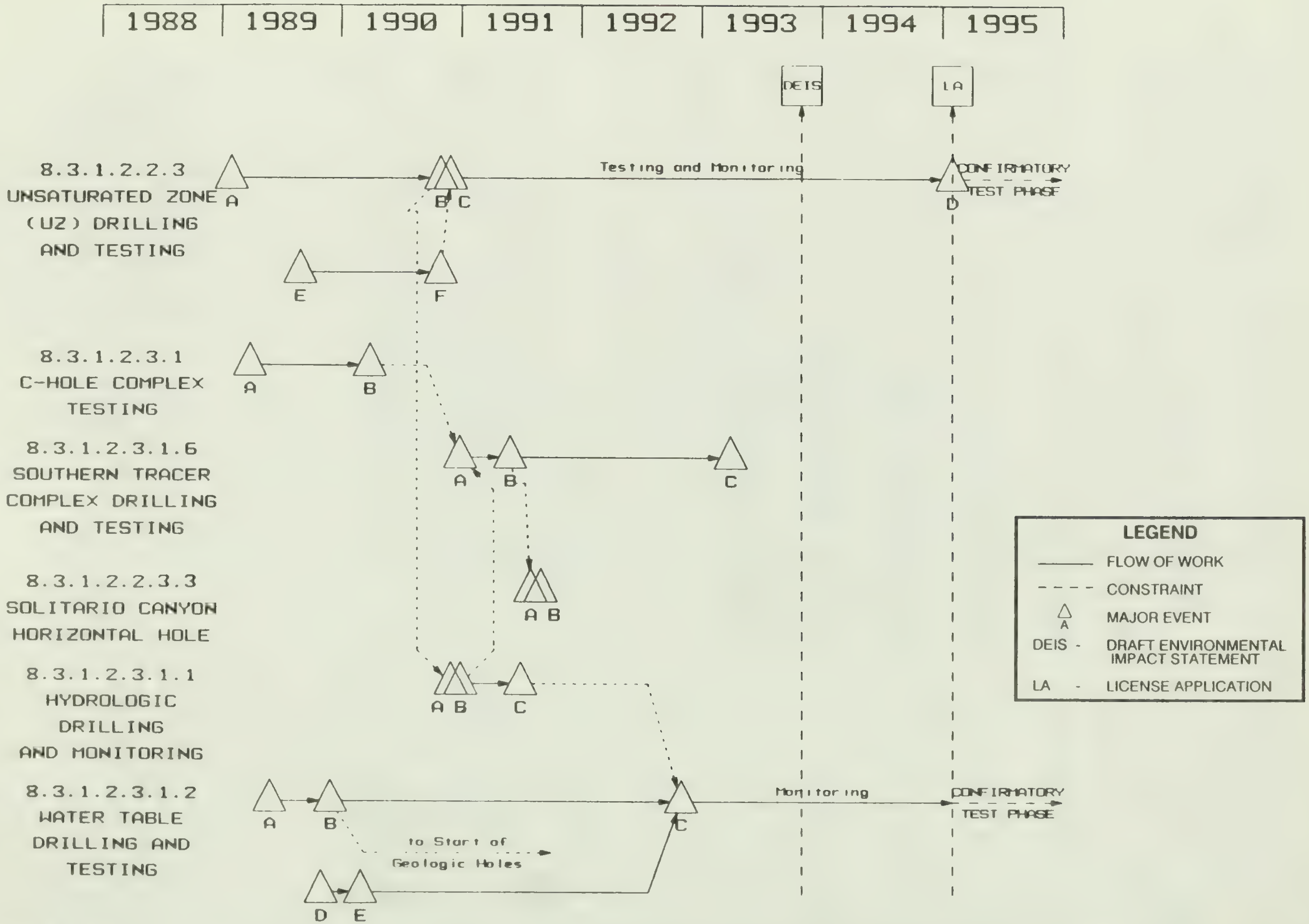


**Figure 8.5-15.** Summary schedule for the surface-based drilling and testing. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 3)

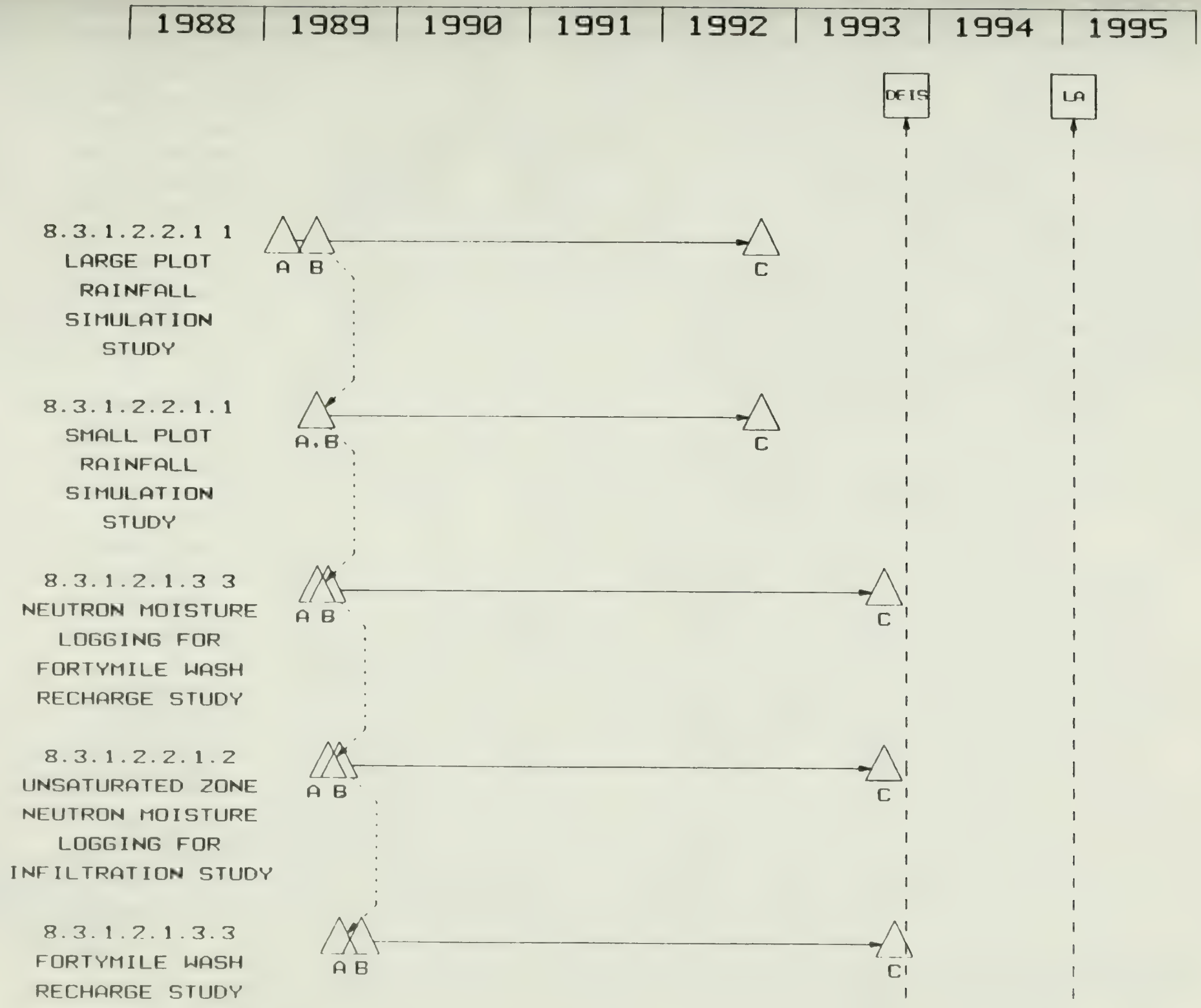


**Figure 8.5-15.** Summary schedule for the surface based drilling and testing This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available (page 2 of 3)

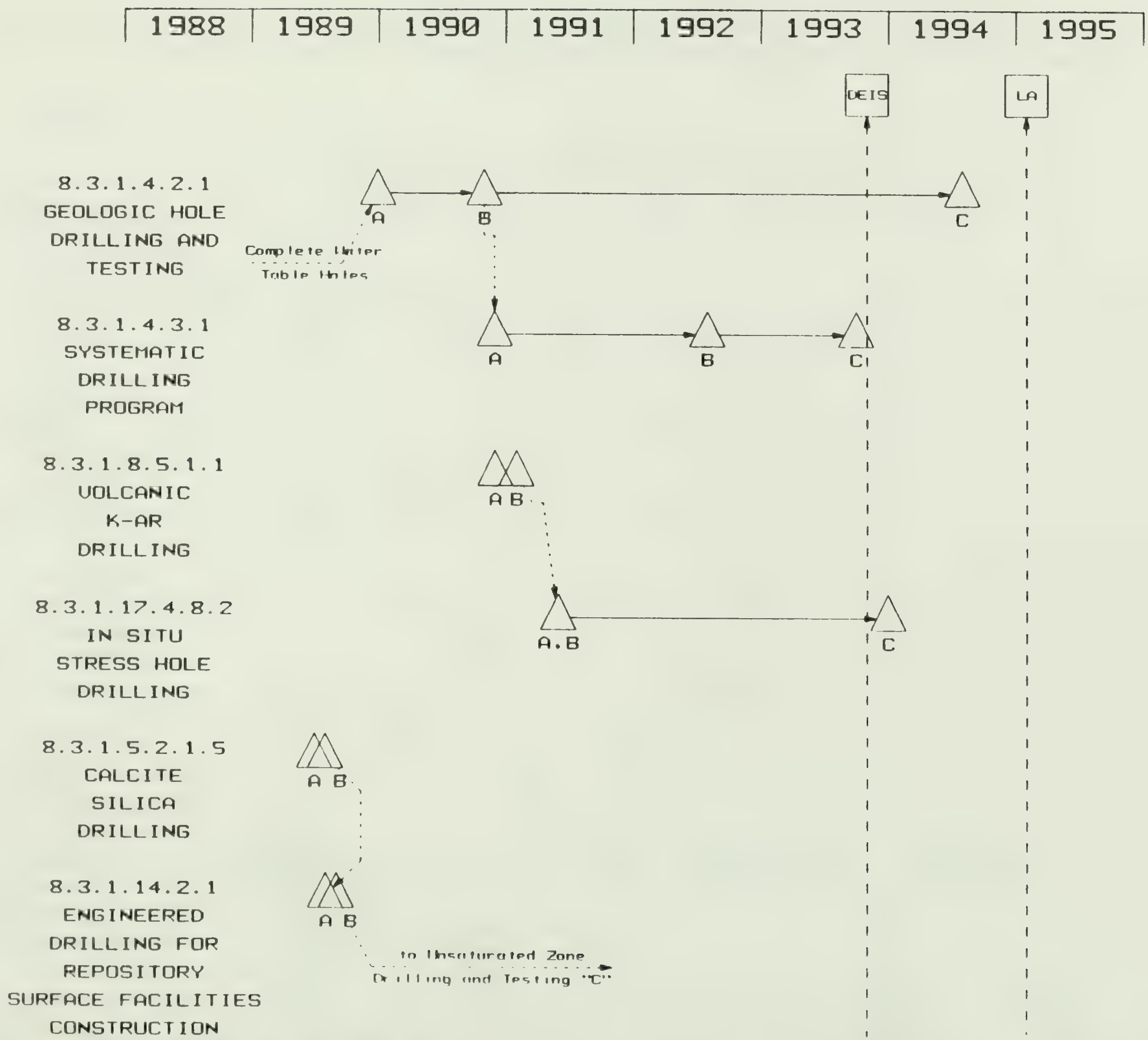


**Figure 8.5-15.** Summary schedule for the surface-based drilling and testing. This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available (page 3 of 3)

Table 8.5-1. Summary schedule for surface-based drilling and testing (page 1 of 5)

| Activity | Related SCP section | Event number | Event description | Date |
|---|---|---|---|---|
| Unsaturated zone (UZ) drilling and testing | 8.3.1.2.2.3 | A | Begin drilling deep unsturated zone (UZ) holes[a] | 2/89 |
| | 8.3.1.2.2.3 | B | Complete drilling of deep UZ holes | 10/90 |
| | 8.3.1.2.2.3 | C | Instrument drillholes and initiate monitoring | 11/90 |
| | 8.3.1.2.2.3 | D | UZ boreholes testing and monitoring complete[b] | 1/95 |
| | 8.3.1.2.2.3 | E | Begin drilling new UZ holes and preparing existing UZ holes for percolation testing and monitoring | 8/89 |
| | 8.3.1.2.2.3 | F | Complete drilling new UZ holes and preparing existing UZ holes for percolation testing and monitoring | 10/90 |
| C-hole complex testing | 8.3.1.2.3.1 | A | Begin C-hole complex testing | 3/89 |
| | 8.3.1.2.3.1 | B | Complete C-hole complex testing[c] | 3/90 |
| Southern Tracer Complex drilling and testing | 8.3.1.2.3.1.6 | A | Begin drilling Southern Tracer complex holes | 12/90 |
| | 8.3.1.2.3.1.6 | B | Complete drilling Southern Tracer Complex holes | 5/91 |
| | 8.3.1.2.3.1.6 | C | Complete testing of Southern Tracer Complex holes | 3/93 |

Table 8.5-1. Summary schedule for surface-based drilling and testing (page 2 of 5)

| Activity | Related SCP section | Event number | Event description | Date |
|---|---|---|---|---|
| Solitario Canyon horizontal hole drilling | 8.3.1.2.2.3.3 | A | Begin drilling Solitario Canyon hole | 7/91 |
| | 8.3.1.2.2.3.3 | B | Complete drilling Solitario Canyon hole | 8/91 |
| Hydrologic drilling and monitoring | 8.3.1.2.3.1.1 | A | Begin drilling hydrologic test hole for Solitario Canyon fault study | 11/90 |
| | 8.3.1.2.3.1.1 | B | Complete drilling hydrologic test hole | 12/90 |
| | 8.3.1.2.3.1.1 | C | Estimated completion of tests in the hydrologic test hole[d]; water table monitoring will continue[e] | 6/91 |
| Water table drilling and testing | 8.3.1.2.3.1.2 | A | Begin drilling water table holes | 5/89 |
| | 8.3.1.2.3.1.2 | B | Complete drilling of water table holes | 11/89 |
| | 8.3.1.2.3.1.2 | C | Complete potentiometric measurements in water table holes; potentiometric-level monitoring will continue[e] | 10/92 |
| | 8.3.1.2.3.1.2 | D | Begin testing existing water table holes | 10/89 |
| | 8.3.1.2.3.1.2 | E | Complete testing existing water table holes | 2/90 |
| Large plot rainfall simulation (LPRS) study | 8.3.1.2.2.1.1 | A | Begin drilling LPRS holes | 2/89 |
| | 8.3.1.2.2.1.1 | B | Complete drilling LPRS holes | 5/89 |

Table 8.5-1. Summary schedule for surface-based drilling and testing (page 3 of 5)

| Activity | Related SCP section | Event number | Event description | Date |
|---|---|---|---|---|
| | 8.3.1.2.2.1.1 | C | Complete testing LPRS holes | 9/92 |
| Small plot rainfall simulation (SPRS) study | 8.3.1.2.2.1.1 | A | Begin drilling SPRS holes | 5/89 |
| | 8.3.1.2.2.1.1 | B | Complete drilling SPRS holes | 5/89[f] |
| | 8.3.1.2.2.1.1 | C | Complete testing of SPRS holes | 9/92 |
| Neutron moisture logging for Fortymile Wash recharge study | 8.3.1.2.1.3.3 | A | Begin drilling FMN series for neutron moisture logging | 5/89 |
| | 8.3.1.2.1.3.3 | B | Complete drilling FMN series for neutron moisture logging | 6/89 |
| | 8.3.1.2.1.3.3 | C | Complete Fortymile Wash neutron logging | 8/93 |
| Unsaturated zone neutron moisture logging for infiltration study | 8.3.1.2.2.1.2 | A | Begin drilling neutron holes | 6/89 |
| | 8.3.1.2.2.1.2 | B | Complete drilling neutron holes | 7/89 |
| | 8.3.1.2.2.1.2 | C | Complete UZ infiltration logging | 8/93 |
| Fortymile Wash recharge study | 8.3.1.2.1.3.3 | A | Begin drilling Fortymile Wash recharge study holes | 7/89 |
| | 8.3.1.2.1.3.3 | B | Complete drilling of Fortymile Wash recharge study holes | 9/89 |
| | 8.3.1.2.1.3.3 | C | Complete testing of Fortymile Wash recharge study holes | 9/93 |

Table 8.5-1. Summary schedule for surface-based drilling and testing (page 4 of 5)

| Activity | Related SCP section | Event number | Event description | Date |
|---|---|---|---|---|
| Geologic hole drilling and testing | 8.3.1.4.2.1 | A | Begin drilling geologic holes | 12/89 |
| | 8.3.1.4.2.1 | B | Complete drilling geologic holes | 10/90 |
| | 8.3.1.4.2.1 | C | Complete testing of geologic holes | 7/94 |
| Systematic drilling program | 8.3.1.4.3.1 | A | Begin performance assessment-based systematic drilling program | 11/90 |
| | 8.3.1.4.3.1 | B | Complete drilling boreholes of the systematic drilling program | 7/92 |
| | 8.3.1.4.3.1 | C | Complete testing and evaluation of systematic drilling program boreholes | 9/93 |
| Volcanic K-Ar drilling | 8.3.1.8.5.1.1 | A | Begin drilling volcanic holes | 11/90 |
| | 8.3.1.8.5.1.1 | B | Complete drilling volcanic holes | 1/91 |
| In situ stress hole drilling | 8.3.1.17.4.8.2 | A | Begin drilling in situ stress hole | 5/91 |
| | 8.3.1.17.4.8.2 | B | Complete drilling in situ stress hole | 5/91[g] |
| | 8.3.1.17.4.8.2 | C | Estimated completion of in situ stress hole testing[d] | 12/93 |
| Calcite-silica drilling | 8.3.1.5.2.1.5 | A | Begin Ca-Si drilling | 6/89 |
| | 8.3.1.5.2.1.5 | B | Complete Ca-Si drilling | 7/89 |

Table 8.5-1. Summary schedule for surface-based drilling and testing (page 5 of 5)

| Activity | Related SCP section | Event number | Event description | Date |
|---|---|---|---|---|
| Engineered drilling for repository surface facilities construction | 8.3.1.14.2.1 | A | Begin drilling exploratory shaft facility (ESF) series of test holes for engineering design assessment | 7/89 |
| | 8.3.1.14.2.1 | B | Complete drilling ESF series of test holes | 8/89 |

[a]Deep holes are >1500 ft in depth.

[b]Site vertical boreholes/UZ boreholes monitoring will be continued beyond January 1995 as performance confirmation.

[c]Results of C-hole complex testing will determine whether Southern Tracer Complex test holes are drilled.

[d]In situ stress testing may also be done in the geologic and hydrologic boreholes.

[e]Site potentiometric-level monitoring will continue beyond January 1995 as performance confirmation.

[f]Total drilling time for SPRS wells expected to be about three weeks.

[g]Total drilling time for in situ stress hole approximately two weeks.

Table 8.5-2. Site characterization study plans

| Study plan number[a] | Study plan title[b] |
|---|---|
| | GEOHYDROLOGY PROGRAM |
| 8.3.1.2.1.1 | Characterization of the Meteorology for Regional Hydrology |
| 8.3.1.2.1.2 | Characterization of Runoff and Streamflow |
| 8.3.1.2.1.3 | Characterization of the Regional Ground-Water Flow System |
| 8.3.1.2.1.4 | Regional Hydrologic System Synthesis and Modeling |
| 8.3.1.2.2.1 | Characterization of Unsaturated-Zone Infiltration |
| 8.3.1.2.2.2 | Water Movement Tracer Tests Using Chloride and Chlorine-36 Measurements of Percolation at Yucca Mountain |
| 8.3.1.2.2.3 | Characterization of Percolation in the Unsaturated Zone - Surface-Based Study |
| 8.3.1.2.2.4 | Characterization of Yucca Mountain Percolation in the Unsaturated Zone--Exploratory Shaft Facility Study |
| 8.3.1.2.2.5 | Diffusion Tests in the Exploratory Shaft Facility |
| 8.3.1.2.2.6 | Characterization of Gaseous-Phase Movement in the Unsaturated Zone |
| 8.3.1.2.2.7 | Hydrochemical Characterization of the Unsaturated Zone |
| 8.3.1.2.2.8 | Fluid Flow in Unsaturated, Fractured Rock |
| 8.3.1.2.2.9 | Site Unsaturated-Zone Modeling and Synthesis |
| 8.3.1.2.3.1 | Characterization of the Site Saturated-Zone Ground-Water Flow System |
| 8.3.1.2.3.2 | Characterization of the Saturated-Zone Hydrochemistry |
| 8.3.1.2.3.3 | Saturated-Zone Hydrologic System Synthesis and Modeling |
| | GEOCHEMISTRY PROGRAM |
| 8.3.1.3.1.1 | Ground-Water Chemistry Model |
| 8.3.1.3.2.1 | Mineralogy, Petrology, and Chemistry of Transport Pathways |

Table 8.5-2. Site characterization study plans (continued)

| Study plan number[a] | Study plan title[b] |
|---|---|
| | GEOCHEMISTRY PROGRAM (continued) |
| 8.3.1.3.2.2 | History of Mineralogic and Geochemical Alteration of Yucca Mountain |
| 8.3.1.3.3.1 | Natural Analog of Hydrothermal Systems in Tuff |
| 8.3.1.3.3.2 | Kinetics and Thermodynamics of Mineral Evolution |
| 8.3.1.3.3.3 | Conceptual Model of Mineral Evolution |
| 8.3.1.3.4.1 | Batch Sorption Studies |
| 8.3.1.3.4.2 | Biological Sorption and Transport |
| 8.3.1.3.4.3 | Development of Sorption Models |
| 8.3.1.3.5.1 | Dissolved Species Concentration Limits |
| 8.3.1.3.5.2 | Colloid Behavior |
| 8.3.1.3.6.1 | Dynamic Transport Column Experiments |
| 8.3.1.3.6.2 | Diffusion |
| 8.3.1.3.7.1 | Retardation Sensitivity Analysis |
| 8.3.1.3.7.2 | Demonstration of Applicability of Laboratory Data to Repository Transport Calculations |
| 8.3.1.3.8.1 | Gaseous Radionuclide Transport Calculations and Measurements |
| | ROCK CHARACTERISTICS PROGRAM (POSTCLOSURE) |
| 8.3.1.4.2.1 | Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area |
| 8.3.1.4.2.2 | Characterization of the Structural Features Within the Site Area |
| 8.3.1.4.2.3 | Three-Dimensional Geologic Model |

Table 8.5-2. Site characterization study plans (continued)

| Study plan number[a] | Study plan title[b] |
|---|---|
| | ROCK CHARACTERISTICS PROGRAM (POSTCLOSURE) (continued) |
| 8.3.1.4.3.1 | Systematic Acquisition of Site-Specific Subsurface Information |
| 8.3.1.4.3.2 | Three-Dimensional Rock Characteristics Models |
| | CLIMATE PROGRAM |
| 8.3.1.5.1.1 | Characterization of Modern Regional Climate |
| 8.3.1.5.1.2 | Paleoclimate Study: Lake, Playa, Marsh Deposits |
| 8.3.1.5.1.3 | Climatic Implications of Terrestrial Paleoecology |
| 8.3.1.5.1.4 | Analysis of the Paleoenvironmental History of the Yucca Mountain Region |
| 8.3.1.5.1.5 | Paleoclimate-Paleoenvironmental Synthesis |
| 8.3.1.5.1.6 | Characterization of the Future Regional Climate and Environments |
| 8.3.1.5.2.1 | Characterization of the Quaternary Regional Hydrology |
| 8.3.1.5.2.2 | Characterization of the Future Regional Hydrology due to Climate Changes |
| | EROSION PROGRAM |
| 8.3.1.6.1.1 | Distribution and Characteristics of Present and Past Erosion |
| 8.3.1.6.2.1 | Influence of Future Climatic Conditions on Locations and Rates of Erosion |
| 8.3.1.6.3.1 | Evaluation of the Effects of Future Tectonic Activity on Erosion at Yucca Mountain |
| 8.3.1.6.4.1 | Development of a Topical Report to Address the Effects of Erosion on the Hydrologic, Geochemical, and Rock Characteristics at Yucca Mountain |

Table 8.5-2. Site characterization study plans (continued)

| Study plan number[a] | Study plan title[b] |
|---|---|
| | TECTONICS PROGRAM (POSTCLOSURE) |
| 8.3.1.8.1.1 | Probability of a Volcanic Eruption Penetrating the Repository |
| 8.3.1.8.1.2 | Effects of Volcanic Eruption Penetrating the Repository |
| 8.3.1.8.2.1 | Analysis of Waste Package Rupture due to Tectonic Processes and Events |
| 8.3.1.8.3.1 | Analysis of the Effects of Tectonic Processes and Events on Average Percolation Flux Rates Over the Repository |
| 8.3.1.8.3.2 | Analysis of the Effects of Tectonic Processes and Events on Changes in Water-Table Elevation |
| 8.3.1.8.3.3 | Analysis of the Effects of Tectonic Processes and Events on Local Fracture Permeability and Effective Porosity |
| 8.3.1.8.4.1 | Analysis of the Effects of Tectonic Processes and Events on Rock Geochemical Properties |
| 8.3.1.8.5.1 | Characterization of Volcanic Features |
| 8.3.1.8.5.2 | Characterization of Igneous Intrusive Features |
| 8.3.1.8.5.3 | Investigation of Folds in Miocene and Younger Rocks of the Region |
| | HUMAN INTERFERENCE PROGRAM |
| 8.3.1.9.1.1 | An Evaluation of Natural Processes That Could Affect the Long-Term Survivability of the Surface Marker System at Yucca Mountain |
| 8.3.1.9.2.1 | Natural Resource Assessment of Yucca Mountain, Nye County, Nevada |
| 8.3.1.9.2.2 | Water Resource Assessment of Yucca Mountain, Nevada |
| 8.3.1.9.3.1 | Evaluation of Data Needed to Support an Assessment of the Likelihood of Future Inadvertent Human Intrusion at Yucca Mountain as a Result of Exploration and/or Extraction of Natural Resources |

Table 8.5-2. Site characterization study plans (continued)

| Study plan number[a] | Study plan title[b] |
|---|---|
| | HUMAN INTERFERENCE PROGRAM (continued) |
| 8.3.1.9.3.2 | An Evaluation of the Potential Effects of Exploration for or Extraction of Natural Resources on the Hydrologic Characteristics at Yucca Mountain |
| | METEOROLOGICAL PROGRAM |
| 8.3.1.12.2.1 | Meteorological Data Collection at the Yucca Mountain Site |
| | SURFACE CHARACTERISTICS PROGRAM |
| 8.3.1.14.2.1 | Exploration Program |
| 8.3.1.14.2.2 | Laboratory Tests and Material Property Measurements |
| 8.3.1.14.2.3 | Field Tests and Characterization Measurements |
| | ROCK CHARACTERISTICS PROGRAM (PRECLOSURE) |
| 8.3.1.15.1.1 | Laboratory Thermal Properties |
| 8.3.1.15.1.2 | Laboratory Thermal Expansion Testing |
| 8.3.1.15.1.3 | Laboratory Determination of Mechanical Properties of Intact Rock |
| 8.3.1.15.1.4 | Laboratory Determination of the Mechanical Properties of Fractures |
| 8.3.1.15.1.5 | Excavation Investigations |
| 8.3.1.15.1.6 | In Situ Thermomechanical Properties |
| 8.3.1.15.1.7 | In Situ Mechanical Properties |
| 8.3.1.15.1.8 | In Situ Design Verification |
| 8.3.1.15.2.1 | Characterization of the Site Ambient Stress Conditions |
| 8.3.1.15.2.2 | Characterization of the Site Ambient Thermal Conditions |

Table 8.5-2. Site characterization study plans (continued)

| Study plan number[a] | Study plan title[b] |
|---|---|
| | PRECLOSURE HYDROLOGY PROGRAM |
| 8.3.1.16.1.1 | Characterization of Flood Potential of the Yucca Mountain Site |
| 8.3.1.16.2.1 | Location of Adequate Water Supply for Construction, Operation, Closure, and Decommissioning of a Mined Geologic Disposal System at Yucca Mountain, Nevada |
| 8.3.1.16.3.1 | Determination of Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada |
| | TECTONICS PROGRAM (PRECLOSURE) |
| 8.3.1.17.1.1 | Potential for Ash Fall at the Site |
| 8.3.1.17.2.1 | Faulting Potential at the Repository |
| 8.3.1.17.3.1 | Relevant Earthquake Sources |
| 8.3.1.17.3.2 | Underground Nuclear Explosion Sources |
| 8.3.1.17.3.3 | Ground Motion from Regional Earthquakes and Underground Nuclear Explosions |
| 8.3.1.17.3.4 | Effects of Local Site Geology on Surface and Subsurface Motions |
| 8.3.1.17.3.5 | Ground Motion at the Site from Controlling Seismic Events |
| 8.3.1.17.3.6 | Probabilistic Seismic Hazards Analyses |
| 8.3.1.17.4.1 | Historical and Current Seismicity |
| 8.3.1.17.4.2 | Location and Recency of Faulting Near Prospective Surface Facilities |
| 8.3.1.17.4.3 | Quaternary Faulting Within 100 km of Yucca Mountain, Including the Walker Lane |
| 8.3.1.17.4.4 | Quaternary Faulting Proximal to the Site Within Northeast-Trending Fault Zones |
| 8.3.1.17.4.5 | Detachment Faults at or Proximal to Yucca Mountain |
| 8.3.1.17.4.6 | Quaternary Faulting Within the Site Area |

Table 8.5-2. Site characterization study plans (continued)

| Study plan number[a] | Study plan title[b] |
|---|---|
| | TECTONICS PROGRAM (PRECLOSURE) (continued) |
| 8.3.1.17.4.7 | Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain |
| 8.3.1.17.4.8 | Stress Field Within and Proximal to the Site Area |
| 8.3.1.17.4.9 | Tectonic Geomorphology of the Yucca Mountain Region |
| 8.3.1.17.4.10 | Geodetic Leveling |
| 8.3.1.17.4.11 | Characterization of Regional Lateral Crustal Movement |
| 8.3.1.17.4.12 | Tectonic Models and Synthesis |
| | SHAFT AND BOREHOLE SEAL CHARACTERISTICS |
| 8.3.3.2.2.1 | Seal Material Properties Development |
| | WASTE PACKAGE CHARACTERISTICS |
| 8.3.4.2.4.1 | Characterize Chemical and Mineralogical Changes in the Postemplacement Environment |
| 8.3.4.2.4.2 | Hydrologic Properties of Waste Package Environment |
| 8.3.4.2.4.3 | Mechanical Attributes of the Waste |
| 8.3.4.2.4.4 | Engineered Barrier System Field Tests |

[a]Study plan number corresponds to the SCP section number under which a discussion of the study is provided.
[b]Study plan title corresponds to the appropriate SCP section title.

Study plans are being prepared to be consistent with agreements between the DOE and the NRC. Detailed technical and compliance reviews will be completed by the DOE. Following these reviews, study plans will then be submitted to the NRC for review and to the State for information.

## 8.5.2 PERFORMANCE ASSESSMENT ACTIVITIES AND MILESTONES

The elements of performance assessment for a high-level radioactive waste repository can be categorized into calculations covering two distinctly different time periods. The first time period, referred to as the preclosure period, covers the period during repository operation, closure and decommissioning. Calculations must demonstrate compliance with the radiation exposure and radioactive material release limits for the unrestricted area and the exposure limits for repository workers during the period of waste emplacement and until final closure and decommissioning of the repository. The preclosure radiological safety requirements are discussed in Sections 8.3.5.3, 8.3.5.4, and 8.3.5.5. In addition, as required by 10 CFR 60.111, the repository must be designed, constructed, operated, closed, and decommissioned so that the retrieval option will be maintained. This requirement is discussed in Section 8.3.5.2.

The second time period covered by performance assessment calculations is termed the postclosure period, which represents the time following permanent closure of the repository. Calculated releases from the repository must meet the limits specified by the NRC in 10 CFR Part 60. The postclosure performance requirements are summarized in Section 8.3.5.8. Performance requirements apply to the overall geologic repository, the engineered barrier system, the geologic setting (natural barriers), and the waste package.

The following sections provide summary schedule information associated with the performance assessment issues presented in Section 8.3.5. Schedule information for preclosure and postclosure performance assessment is treated separately in Sections 8.5.2.1 and 8.5.2.2, respectively.

### 8.5.2.1 Preclosure performance assessment

Preclosure performance assessment activities address the requirements for controlling occupational and public radiation exposures specified in 10 CFR Part 20, 10 CFR Part 60, and 40 CFR 191, Subpart A, and the requirement for maintenance of the option to retrieve.

Summary schedules for each preclosure performance assessment issue described in Sections 8.3.5.2 through 8.3.5.5 are provided in this section. Information needs within an issue are represented as appropriate. The information need number and brief description are shown on the schedules, as well as major events associated with each information need. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. It should be noted that preliminary data meeting applicable quality assurance requirements (Section 8.6) will be available prior to report availability. Solid lines on the schedules represent information need durations and dashed lines show interfaces among information needs, as well as data transferred into or out of the issue. The schedules assume continuous integration among activities with only major ties shown.

Waste retrievability (Issue 2.4, Section 8.3.5.2)

Summary schedule information for Issue 2.4 is presented in Figure 8.5-16. The activities described in this issue are those addressing the requirement that the repository design, construction, operation, and maintenance must ensure that any or all of the emplaced waste can be retrieved starting at any time up to 50 yr after waste emplacement operations have begun. Activities planned to support resolution of this issue include design analyses and documentation of retrieval conditions for access to waste emplacement boreholes, access to waste containers, borehole access for waste removal, and for transport of retrieved waste to the surface facilities. Issue 4.4 (preclosure design and technical feasibility) integrates the requirements for maintaining the retrieval option from Issue 2.4 with other constraints on repository design addressed in other issues to produce reference designs.

The major events shown on the schedule in Figure 8.5-16 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Complete compilation of site and design requirements to support retrieval | 8/89 |
| B | Complete analysis of site and design data requests | 11/89 |
| C | Complete compilation of retrieval conditions | 8/90 |
| D | Complete report on site and design and design requirements to support retrieval | 8/90 |
| E | Complete compilation of retrieval strategy data required for compliance analysis | 6/89 |
| F | Complete retrieval compliance analysis required for advanced conceptual design (ACD) | 1/92 |
| G | Complete retrieval compliance analysis required for license application design (LAD) | 5/94 |

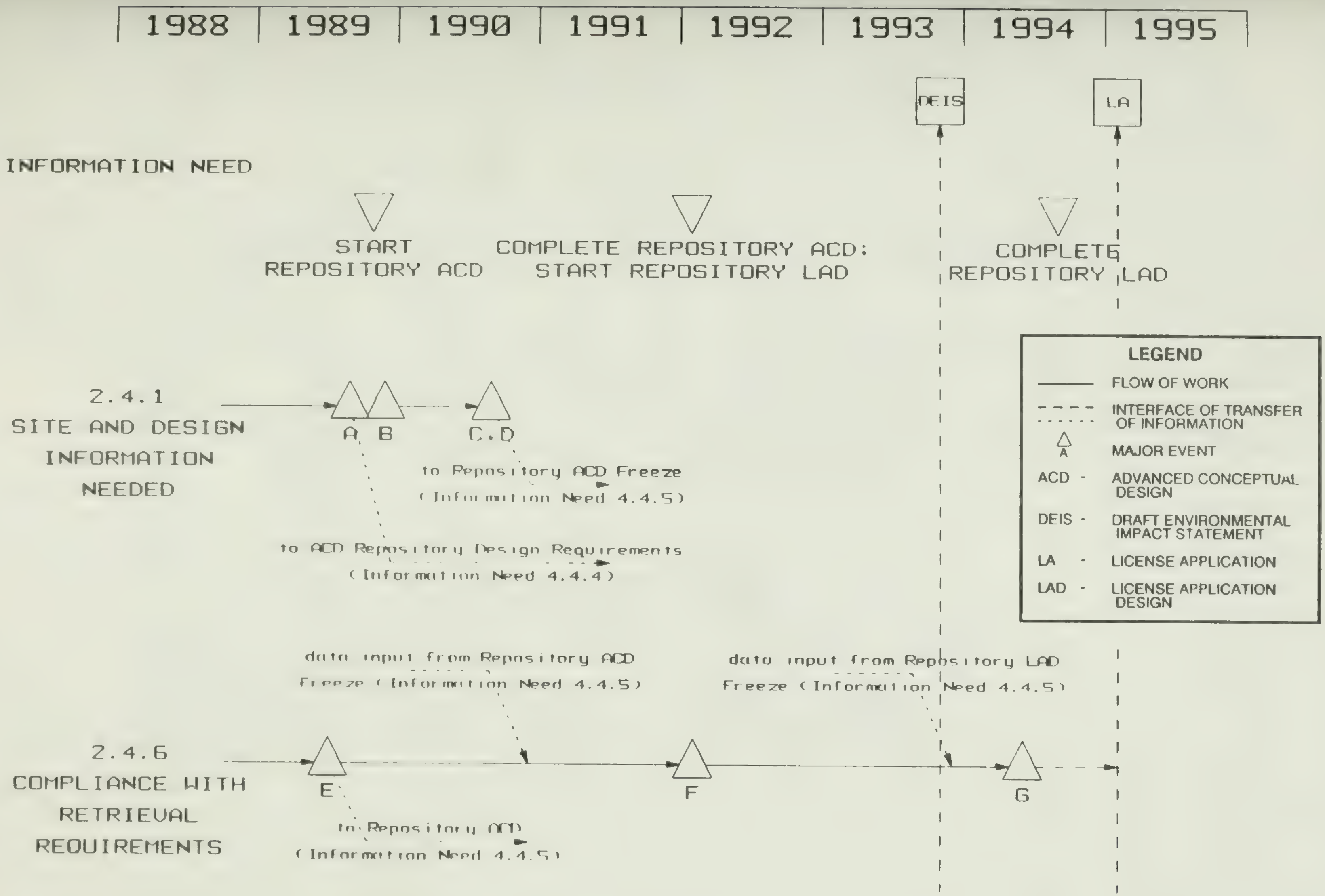


**Figure 8.5-16.** Summary schedule information for the Issue 2.4 (waste retrievability). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

Public radiological exposures--normal conditions (Issue 2.1, Section 8.3.5.3)

Summary schedule information for Issue 2.1 is presented in Figure 8.5-17. The activities planned to support resolution of this issue address the requirements that radiation exposure to the general public associated with normal conditions during operation, closure, and decommissioning of the repository meet the requirements in 10 CFR Part 20 and 40 CFR 191, Subpart A. The activities performed under this issue involve repetitive examination of an evolving design to ensure that the final design meets the established criteria.

The major events shown on the schedule in Figure 8.5-17 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Complete development of performance assessment activities for advanced conceptual design (ACD) preclosure radiological safety through the preclosure risk assessment methodology (PRAM) program; initiate development of assessment activities for license application design (LAD) preclosure radiological safety | 7/89 |
| B | Complete assessment of PRAM program for ACD assessment of public safety | 2/91 |
| C | Complete ACD assessment of public radiological safety using PRAM program method | 1/92 |
| D | Complete development of performance assessment activities for LAD preclosure radiological safety through the PRAM program | 3/93 |
| E | Start LAD assessment of public radiological safety using final PRAM program methods developed | 11/93 |
| F | Final site data feed | 5/94 |
| G | Complete LAD assessment of public radiological safety using final PRAM program methods developed | 8/94 |

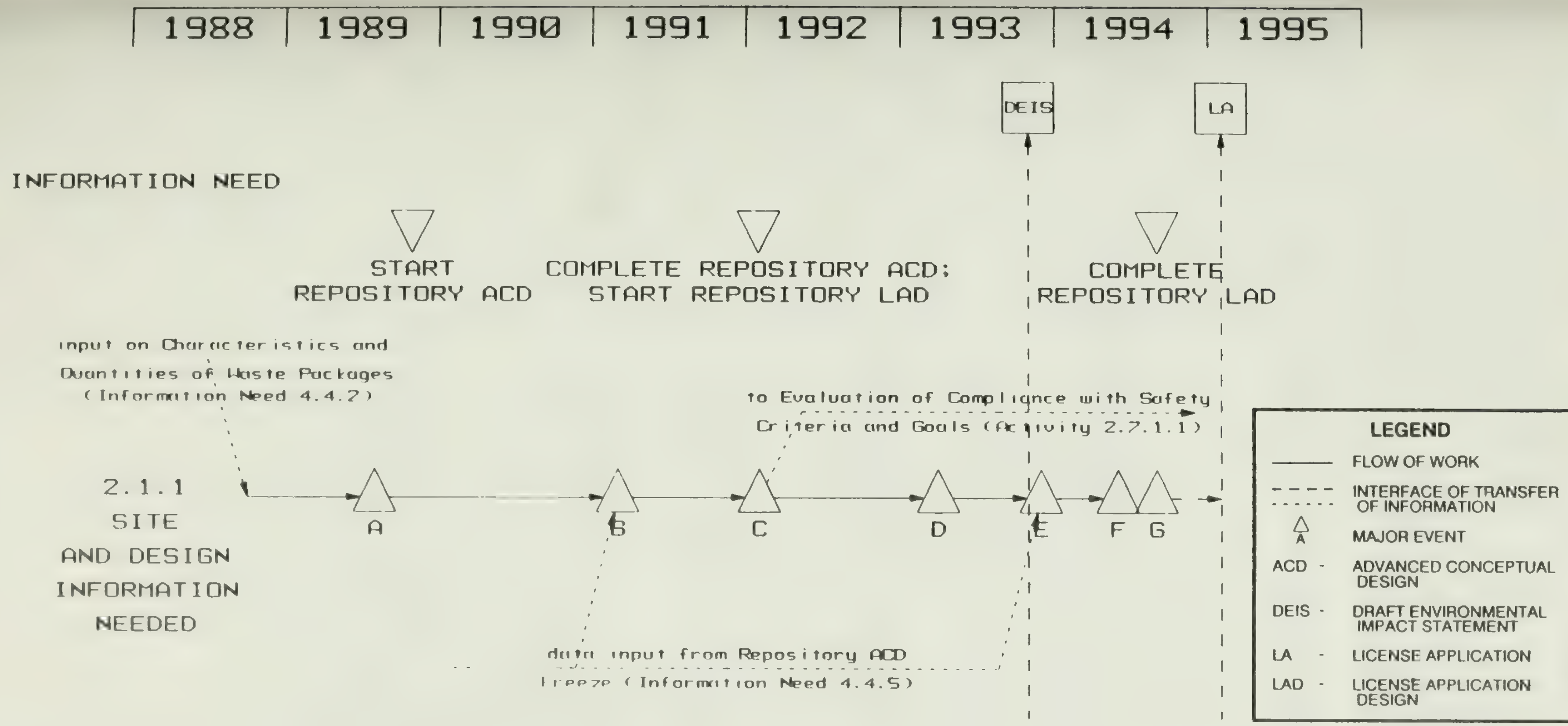


**Figure 8.5-17.** Summary schedule information for the Issue 2.1 (public radiological exposures normal conditions). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available

Worker radiological safety--normal conditions (Issue 2,2, Section 8.3.5.4)

Summary schedule information for Issue 2.2 is presented in Figure 8.5-18. The activities performed under this issue will address the requirement that the radiation doses to workers under normal conditions during construction, operation, closure, and decommissioning of the repository will meet the requirements specified in 10 CFR Part 20.

The major events shown on the schedule in Figure 8.5-18 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Start advanced conceptual design (ACD) assessment of worker radiological safety during normal operations | 12/90 |
| B | Complete ACD assessment of worker radiological safety during normal operations | 7/92 |
| C | Start license application design (LAD) assessment of worker radiological safety during normal operations | 11/93 |
| D | Final site data feed | 6/94 |
| E | Complete LAD assessment of worker radiological safety during normal operations | 8/94 |
| F | Complete development of performance assessment activities for worker radiological safety during normal operations through the preclosure risk assessment methodology (PRAM) program | 5/91 |
| G | PRAM procedure guide available for LAD assessment of worker radiological safety during normal operations | 7/92 |
| H | Final PRAM procedures available to DOE | 9/93 |

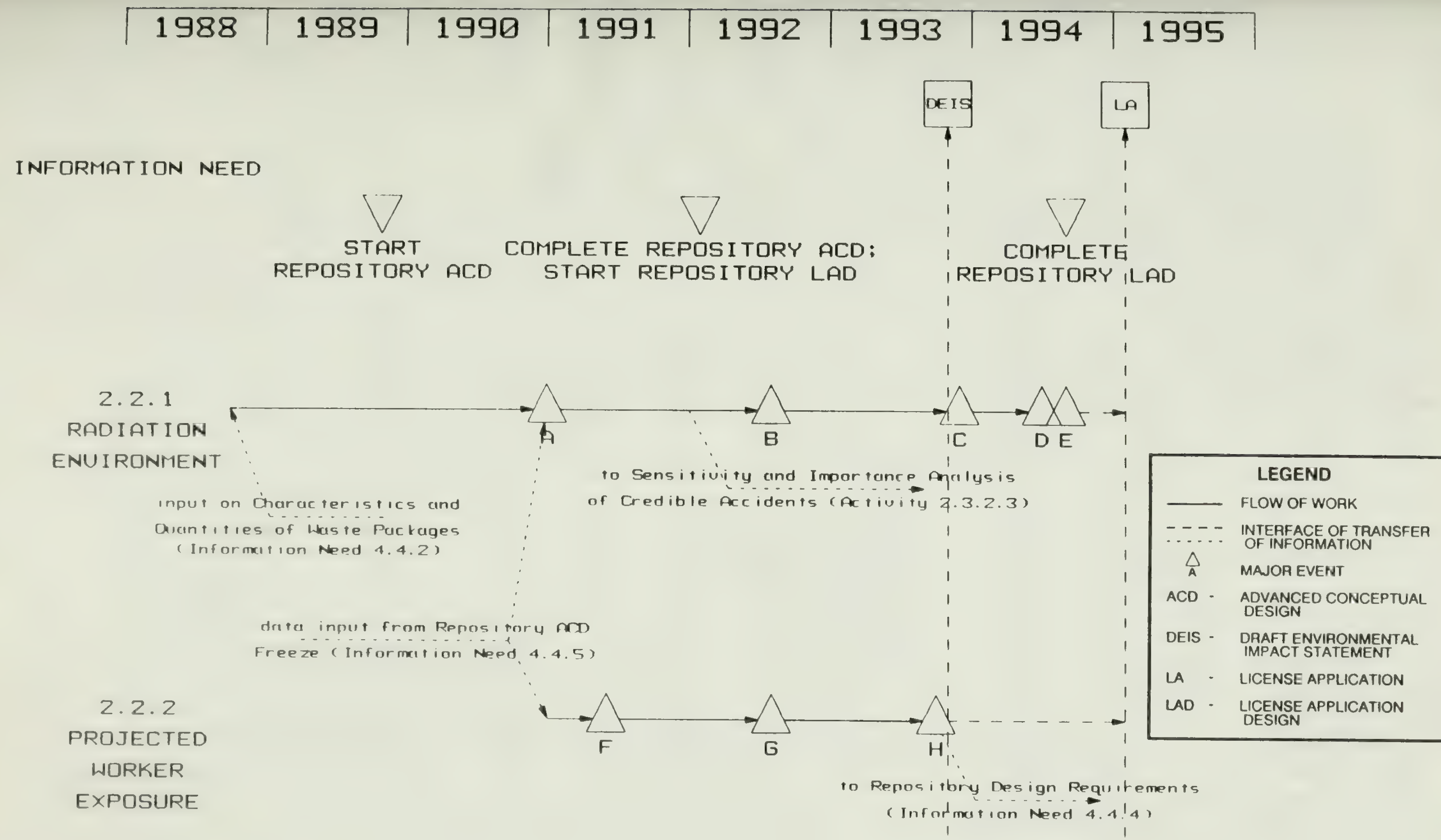


**Figure 8.5-18.** Summary schedule information for the Issue 2 2 (worker radiological safety normal conditions) This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

Accidental radiological releases (Issue 2.3, Section 8.3.5.5)

Summary schedule information for Issue 2.3 is presented in Figure 8.5-19. The activities planned to support resolution of this issue include those necessary to address the requirement that radiation exposure to the general public and repository workers under credible accident conditions during construction, operation, closure and decommissioning must remain at safe levels. The activities to be conducted will demonstrate the adequacy of the structures, systems, and components of the repository to provide for prevention of accidents and mitigation of their consequences. The approach that will be used to protect the health and safety of the general public and repository workers is to provide locations that assist in limiting potential radiation exposure from accidents and provide prevention, containment, and mitigation of accident consequences.

The major events shown on the schedule in Figure 8.5-19 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Complete development of list of credible accident sequences | 11/90 |
| B | Complete development of list of credible design-basis accidents | 3/91 |
| C | Complete assessment of the development methodologies for credible accident sequences | 7/92 |
| D | Complete assessment of the development methodologies for design-basis accidents | 7/92 |
| E | Complete report on credible accident sequences and their respective frequencies | 5/94 |
| F | Complete report on design-basis accidents | 8/94 |
| G | Complete credible accident consequence analysis for advanced conceptual design (ACD) | 6/91 |
| H | Complete credible accident sensitivity analysis | 6/91 |
| I | Complete documentation of the results of safety analyses for ACD | 1/92 |
| J | Initiate documentation of updated credible accident sensitivity analysis | 5/93 |

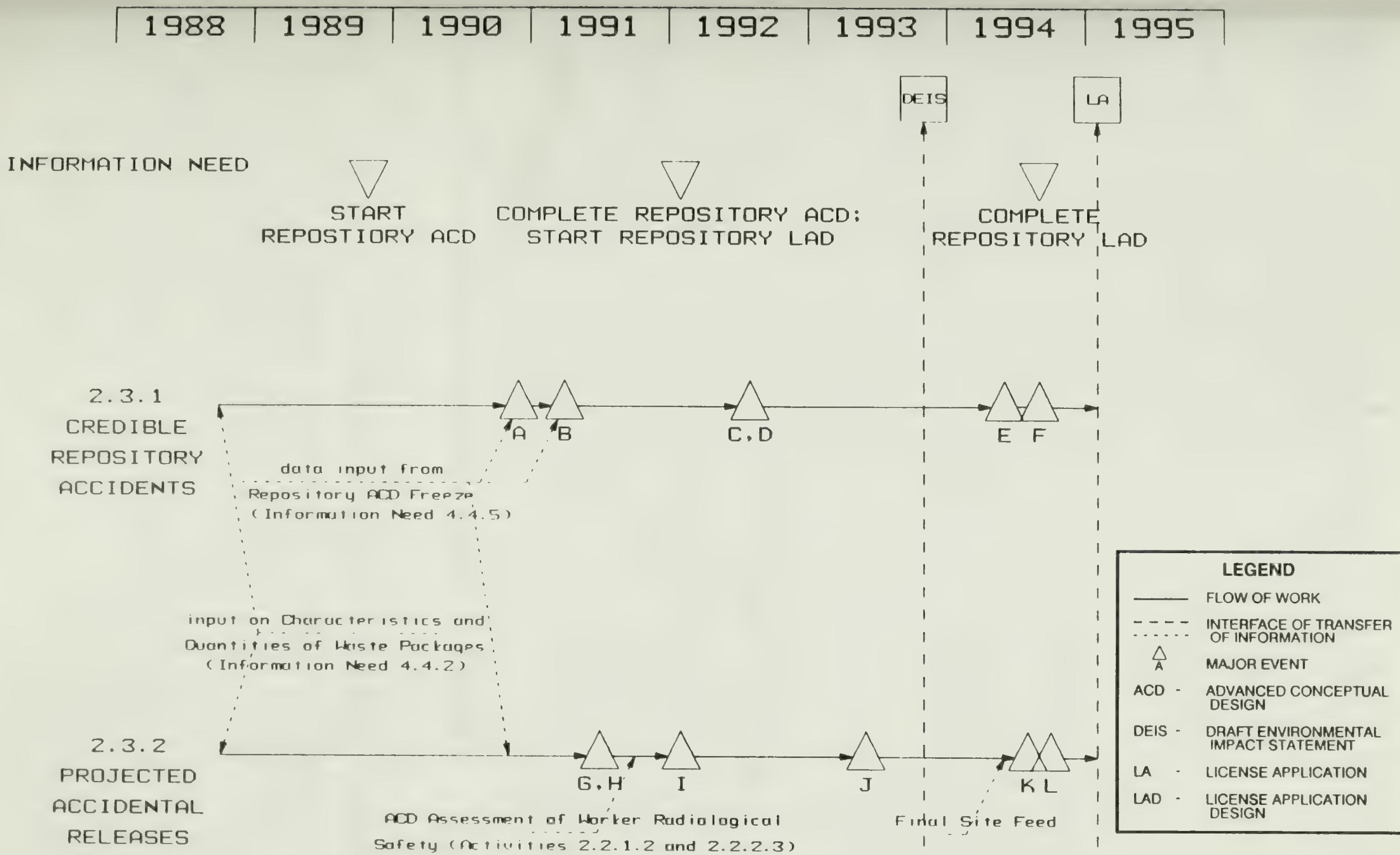


**Figure 8.5-19.** Summary schedule information for the Issue 2 3 (accidental radiological releases) This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Major event | Event description | Date |
|---|---|---|
| K | Final report available to DOE on the consequence analysis of credible accidents for license application design (LAD) | 7/94 |
| L | Complete documentation of safety analyses for LAD | 9/94 |

### 8.5.2.2 Postclosure performance assessment

This section presents summary schedule information for each postclosure performance assessment issue described in Sections 8.3.5.9 through 8.3.5.15. The information presented has been grouped by the principal elements of postclosure performance assessment: overall system performance of the geologic repository, performance of the engineered barrier system and the waste packages, and performance of the geologic setting (natural barriers). These elements represent the primary barriers for which the NRC established performance objectives in 10 CFR 60.112 and 60.113.

#### Overall geologic repository system performance

The requirement for performance of the overall geologic repository system after permanent closure is established in 10 CFR 60.112. This requirement states that the geologic setting shall be selected and the engineered barrier system and the shafts, boreholes, and their seals shall be designed to ensure that releases of radioactive materials to the accessible environment conform to environmental standards for radioactive material release established by the U.S. Environmental Protection Agency (EPA). The EPA has specified limits in 40 CFR 191.13 for total cumulative release of radionuclides over 10,000 yr. Performance assessment calculations will be used to show that releases resulting from both expected conditions and processes and from disturbed conditions and processes will be within the allowable limits.

#### Engineered barrier system and waste package performance

The engineered barrier system (EBS) is to be designed so that assuming anticipated processes and events releases of radionuclides are gradual, resulting in small fractional releases to the geologic setting over long periods of time. The release rate is specified to be not greater than one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 yr after permanent closure of the repository. The EBS is also to be designed so that containment of high level waste will be substantially complete during the period when radiation and thermal conditions are dominated by fission product decay. The waste package is to be designed to provide substantially complete containment of the high level waste for 300 to 1,000 yr after permanent closure of the geologic repository. The major events associated with the waste package and EBS performance issues

(Sections 8.3.5.9 and 8.3.5.10) represent the results of evaluations of releases from various components of the EBS, and reports that document the performance of the waste package in compliance with the requirements previously specified.

Performance of the geologic setting

The performance requirements specified by the NRC in 10 CFR 60.113(a)(ii)(B)(2) for the geologic setting state that the geologic repository should be located so that pre-waste-emplacement ground-water travel time (GWTT) along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment will be at least 1,000 yr. Although this regulation addresses the pre-waste-emplacement ground-water travel time, the calculations for ground-water flow (Section 8.3.5.12) are the same ones used to predict radionuclide migration in the total system performance assessment (Section 8.3.5.13). Therefore, the activities and milestones completed for this component of the performance assessment program serve a dual role although they are more focused toward the assessment of ground-water travel times.

Summary schedules for the issues associated with the principal elements of postclosure performance assessment are provided in this section. Information needs within an issue are represented as appropriate. The information need number and brief description are shown on the schedule, as well as major events associated with each information need. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. It should be noted that preliminary data meeting applicable quality assurance requirements (Section 8.6) will be available prior to report availability. Solid lines on the schedules represent information need durations and dashed lines show interfaces among information needs, as well as data transferred into or out of the issue. The schedules assume continuous integration among activities with only major ties shown.

Containment by waste package (Issue 1.4, Section 8.3.5.9)

Summary schedule information for Issue 1.4 is presented in Figure 8.5-20. The activities planned to support resolution of this issue include those necessary to determine if the set of waste packages will meet the NRC requirement for substantially complete containment for 300 to 1,000 yr. These activities will produce information that allows prediction of both the degree of containment and the duration of containment. The results derived from activities in this issue provide important input to Issue 1.5 (engineered barrier system release rates) and Issue 1.1 (total system performance).

The major events shown on the schedule in Figure 8.5-20 and their planned dates of completion are provided in the following table:

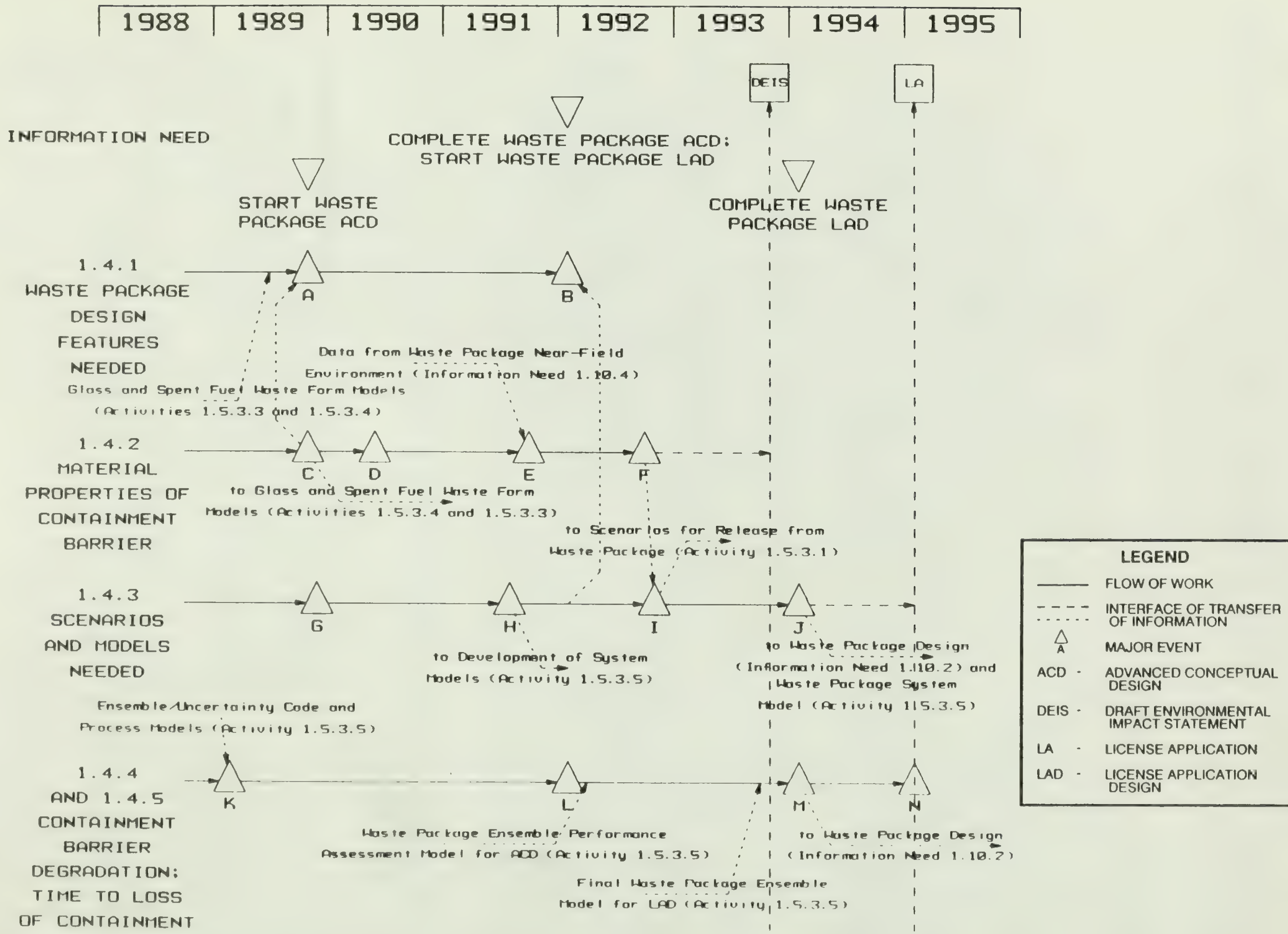


**Figure 8.5-20.** Summary schedule information for the Issue 1 4 (containment by waste package) This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| A | Information on waste packages material selected feeds to waste·package advanced conceptual design (ACD); information on alternative barriers recommended for further testing feeds to waste package ACD | 10/89 |
| B | Final selection of waste package material and design concept feeds to waste package license application design (LAD) | 1/92 |
| C | Metal barrier material selected | 10/89 |
| D | Initiate license application testing of metal barriers | 5/90 |
| E | Complete testing of alternative barriers; results of testing feed to development and testing of materials models | 9/91 |
| F | Complete metal barrier data acquisition to support draft environmental impact statement (DEIS) performance calculations | 9/92 |
| G | Complete corrosion modes model studies | 11/89 |
| H | Complete preliminary metal barrier models | 7/91 |
| I | Provide results of metal barriers testing to waste package performance assessment | 10/92 |
| J | Final report on oxidation and corrosion performance of selected container materials available to DOE | 1/94 |
| K | Begin ensemble and uncertainty analysis for conceptual design following development of uncertainty codes and process models | 2/89 |
| L | Complete performance assessment of waste package ACD | 1/92 |
| M | Complete performance assessment of waste package LAD | 1/94 |
| N | Complete report on LAD ensemble performance for defining source term from waste package | 1/95 |

Engineered barrier system release rates (Issue 1.5, Section 8.3.5.10)

Summary schedule information for Issue 1.5 is presented in Figure 8.5-21. The activities conducted under this issue will support an evaluation of compliance with the requirements of the NRC that the engineered barrier system should limit the release rate of any radionuclide after the containment period so that no greater than one part in 100,000 of the 1,000 yr inventory of that nuclide shall be released per year. The activities that will be performed under this issue include waste form testing, waste package performance assessment, and scenario analysis to provide near-field radionuclide source terms to Issue 1.1 (total system performance).

The major events shown on the schedule in Figure 8.5-21 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to DOE on West Valley glass waste form qualification; begin accumulation of spent fuel and glass waste form data | 3/89 |
| B | Compile current spent fuel, glass waste form, and waste package and repository design information for use in modeling activities | 5/93<br>8/93 |
| C | Initiate dissolution testing of oxidized spent fuel | 10/88 |
| D | Complete spent fuel waste form testing for advanced conceptual design (ACD) | 6/90 |
| E | Complete West Valley glass waste form testing for design | 8/91 |
| F | Draft of final report on oxidation rates and and mechanisms for spent fuel available to DOE | 11/91 |
| G | Complete long-term confirmation dissolution tests on glass waste forms | 8/93 |
| H | Complete documentation of spent fuel waste form testing | 12/93 |
| I | EQ3/6 code release | 3/90 |
| J | Final EQ3/6 code release to DOE | 7/92 |
| K | Finalize deterministic waste package code for license application design (LAD) | 10/93 |

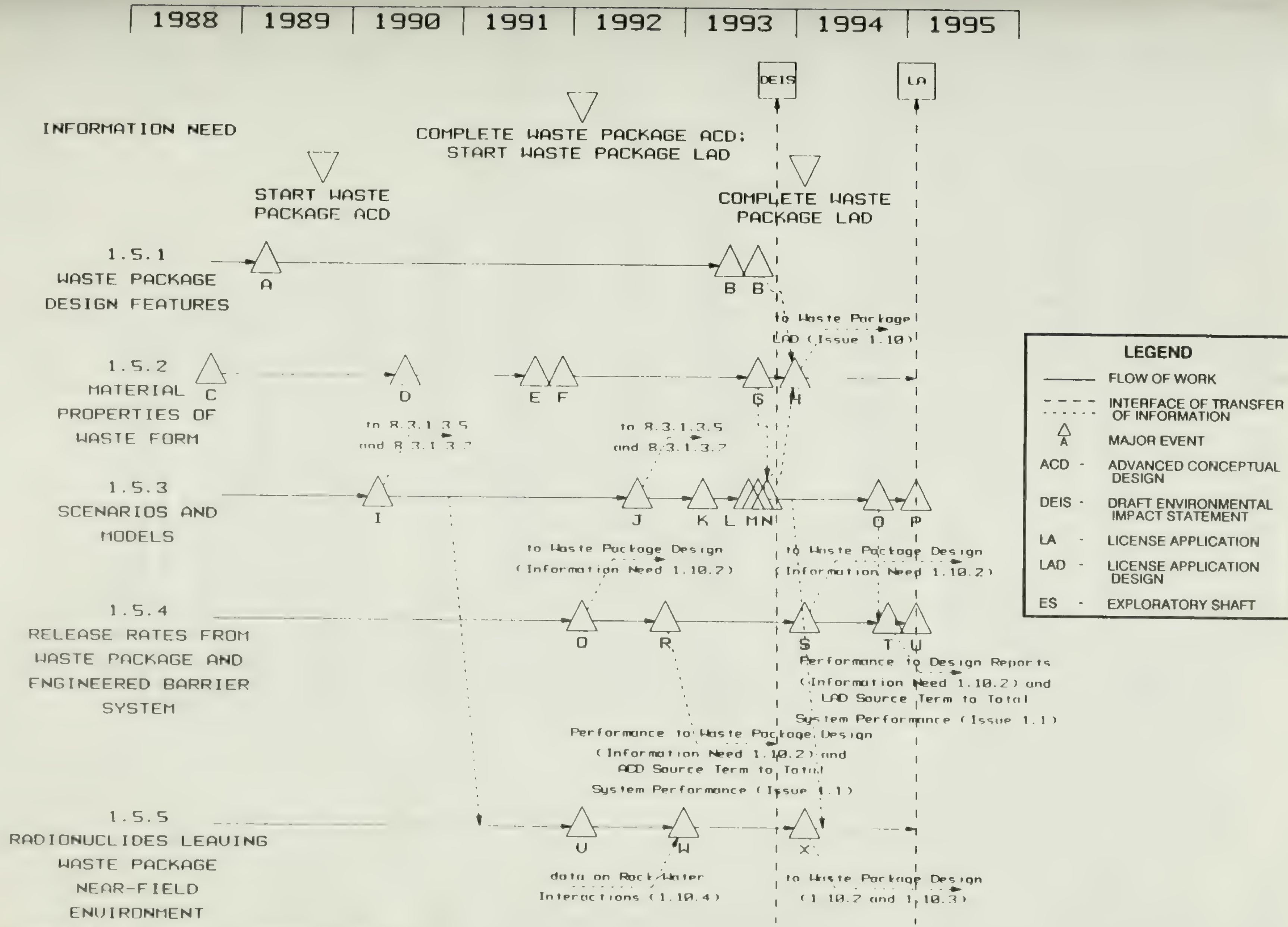


**Figure 8.5-21.** Summary schedule information for the Issue 1.5 (engineered barrier system release rates). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Major event | Event description | Date |
|---|---|---|
| L | Complete integration of scenarios | 8/93 |
| M | Complete modeling of long-term expected performance of spent fuel waste forms under repository conditions | 8/93 |
| N | Complete modeling of long-term performance of glass waste forms under repository conditions | 9/93 |
| O | Complete documentation of waste package assessment codes | 8/94 |
| P | Complete documentation of the verification and validation of waste package assessment codes | 1/95 |
| Q | Complete performance assessment of waste package ACD | 1/92 |
| R | Complete assessment of ACD ensemble performance against regulatory criteria using uncertainty models | 10/92 |
| S | Complete performance assessment of waste package LAD | 1/94 |
| T | Complete analysis of LAD ensemble performance using uncertainty models and analysis of LAD ensemble performance for defining source term from the waste package | 10/94 |
| U | Complete report on LAD ensemble performance for defining source term from the waste package | 1/95 |
| V | Complete investigation of materials interactions among engineered barrier system (EBS) components | 1/92 |
| W | Complete model for integrated testing of waste forms with ground water and container materials | 12/92 |
| X | Complete documentation of radionuclide transport models and results of integrated testing | 1/94 |

Ground-water travel time (Issue 1.6, Section 8.3.5.12)

Summary schedule information for Issue 1.6 is presented in Figure 8.5-22. The activities planned to support resolution of this issue are those required to determine if the pre-waste-emplacement ground-water travel time from the disturbed zone to the accessible environment will be at least 1,000 yr. Because a repository at the Yucca Mountain site would be situated in the unsaturated zone, many of the activities are focused on understanding the dynamics and mechanisms of flow under unsaturated conditions. The NRC regulation responsible for this issue requires that the travel time be calculated along the fastest path of likely radionuclide travel, resulting in some activities to identify the fastest path. This issue also requires a definition of the starting point for the travel-time calculation, i.e., the disturbed zone. Activities necessary to identify the disturbed zone are also included under this issue.

The major events shown on the schedule in Figure 8.5-22 and their planned dates of completion are provided in the following table:

| Major Event | Event Description | Date |
|---|---|---|
| A | Draft report available to DOE on COVE 3 benchmarking | 12/88 |
| B | Draft report available to DOE on the results of preliminary lab studies for validation of the unsaturated zone flow model | 2/89 |
| C | Begin final update/validation of non-isothermal flow models | 1/93 |
| D | Complete certification of computer codes for the calculation of ground-water travel time (GWTT) | 7/93 |
| E | Complete code development | 8/93 |
| F | Final information on the validation and verification of models available for final update of GWTT calculations | 1/94 |
| G | Information on initial analysis of flow paths available for GWTT calculations | 2/89 |
| H | Update of flow path analysis available for updating GWTT calculations | 5/91 |
| I | Final results of flow path analysis available for final update of GWTT calculations | 1/94 |

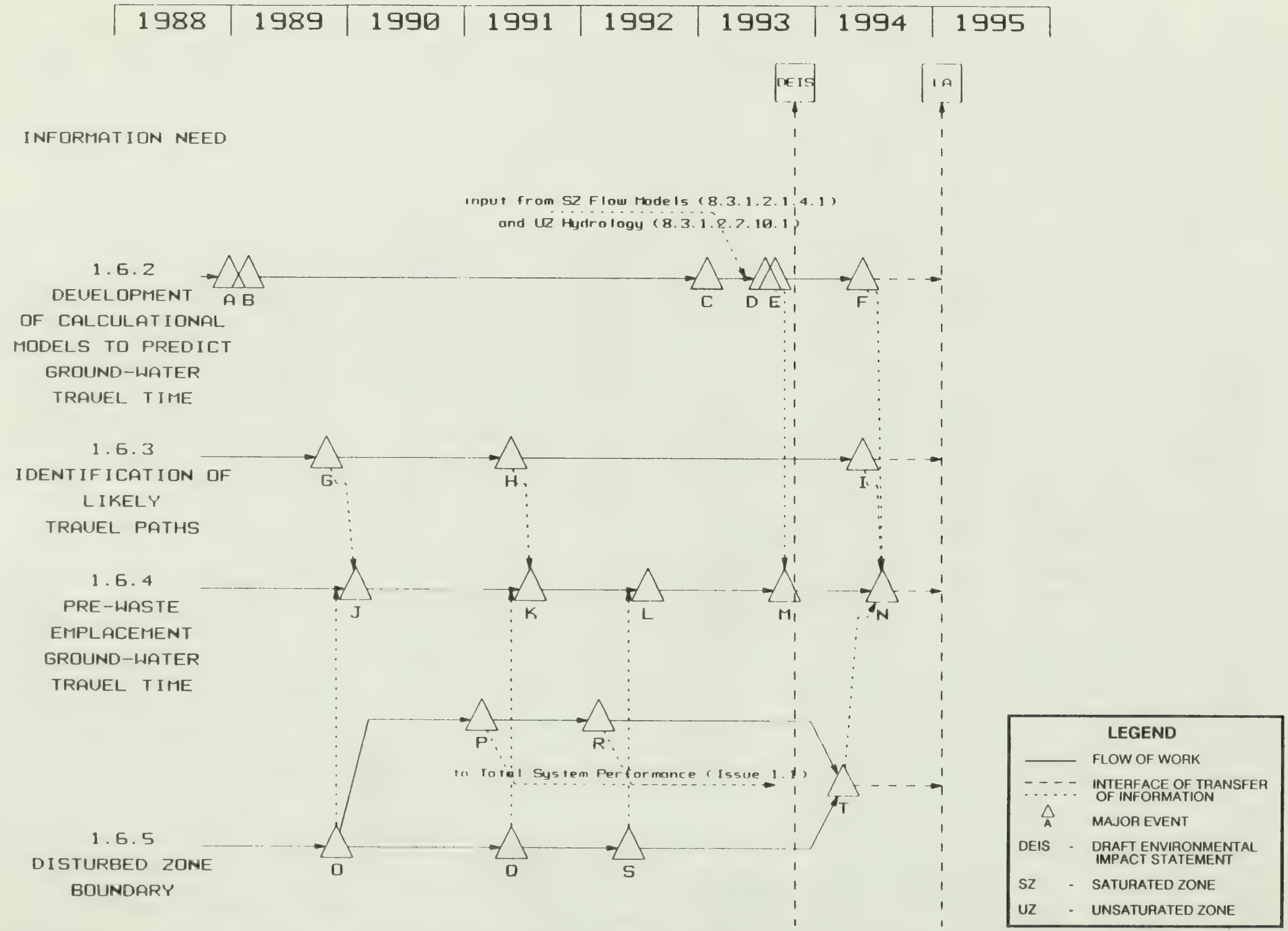


**Figure 8.5-22.** Summary schedule information for the Issue 1.6 (ground-water travel time) This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major Event | Event Description | Date |
|---|---|---|
| J | Draft report available to DOE on the ranges of potential GWTT based on current data | 1/90 |
| K | Draft report available to DOE on the ranges of GWTT based on interim site characterization data | 7/91 |
| L | Draft report available to DOE on preliminary calculations of pre-waste-emplacement GWTT to support the draft environmental impact statement | 7/92 |
| M | Complete updating calculations of pre-waste-emplacement GWTT for final environmental impact statement and license application | 9/93 |
| N | Final report on GWTT calculations available to DOE | 7/94 |
| O | Preliminary definition of disturbed zone available for GWTT calculations | 11/89 |
| P | Complete calculation of post-emplacement GWTT using available site data | 2/91 |
| Q | Updated definition of disturbed zone available for GWTT calculations | 5/91 |
| R | Complete update of post-emplacement GWTT calculations | 2/92 |
| S | Draft report available to DOE on the effects of near-field changes on the disturbed zone definition | 5/92 |
| T | Final report on post-emplacement GWTT and definition of the disturbed zone available to DOE | 3/94 |

Total system performance (Issue 1.1, Section 8.3.5.13)

Summary schedule information for Issue 1.1 is presented in Figure 8.5-23. The activities planned to support resolution of this issue are those necessary to address the requirement that total repository system releases over 10,000 yr must comply with the cumulative release limits specified in 40 CFR Part 191. The contribution of radionuclide releases to the accessible environment for the nominal case, as well as for disturbed scenarios, will be determined. This issue relies on Issue 1.6 (pre-waste-emplacement ground-water travel time) for transport models, and Issue 1.5

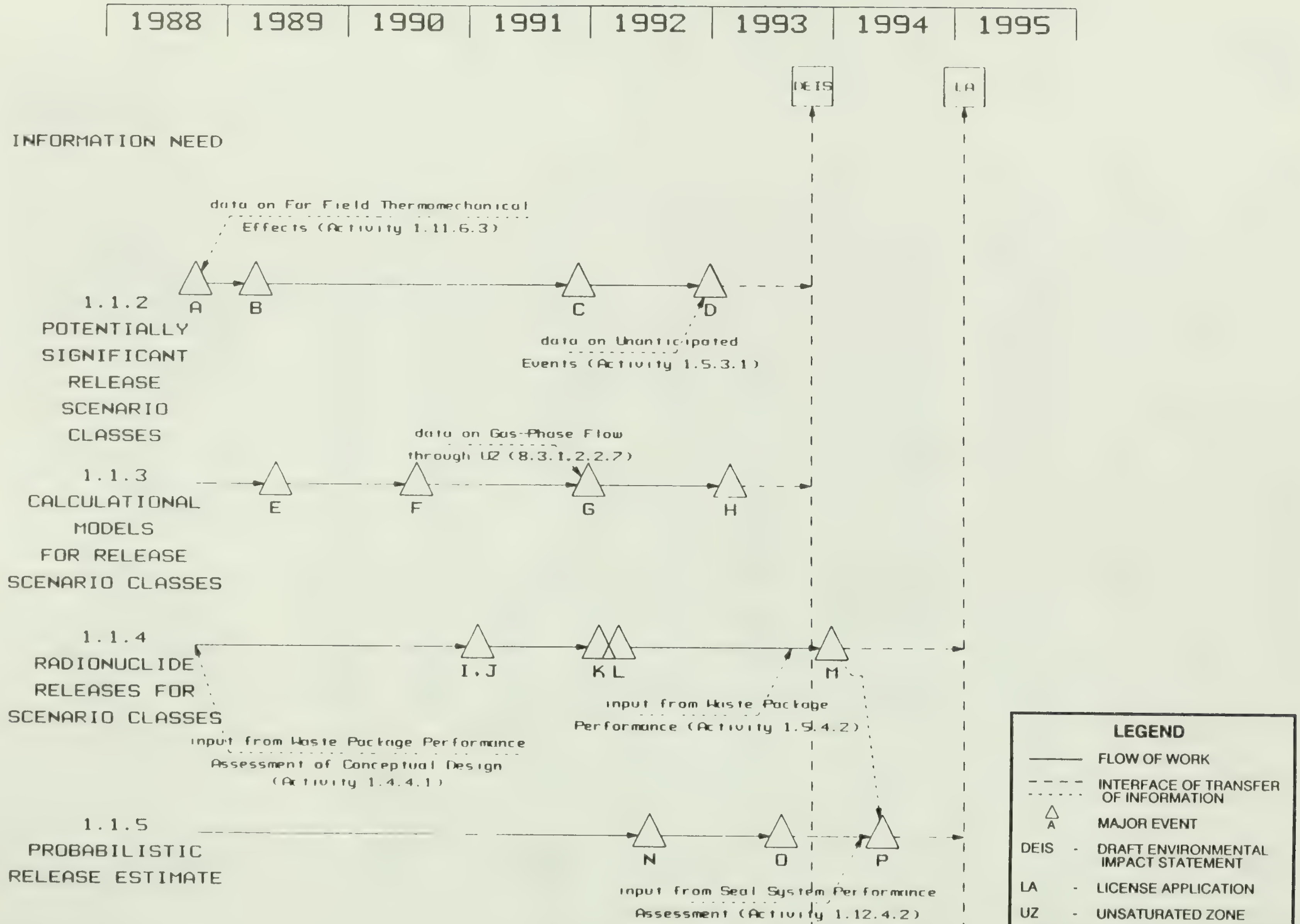


**Figure 8.5-23.** Summary schedule information for the Issue 1.1 (total system performance) This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

(engineered barrier system releases) for radionuclide source terms. It also draws information from a variety of site programs, such as the climate program (Section 8.3.1.5) and the postclosure tectonics program (Section 8.3.1.8) to establish conditions and processes over the next 10,000 yr at the Yucca Mountain site.

The major events shown on the schedule in Figure 8.5-23 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Description of preliminary scenario classes to be screened against consequences | 10/88 |
| B | Complete refinement of potential release-scenario classes based on screening against models; begin refinement based on available site data | 3/89 |
| C | Complete refinement of release-scenario classes | 11/91 |
| D | Draft report available to DOE on final release-scenario classes for input to the DEIS | 12/92 |
| E | Draft report available to DOE on preliminary system models of gas-phase releases | 6/89 |
| F | Draft report available to DOE on preliminary system models of release through water | 7/90 |
| G | Updated water- and gas-release models available | 12/91 |
| H | Complete final water-release model reflecting site characterization input | 3/93 |
| I | Draft report available to DOE on interim screening of release scenario classes | 1/91 |
| J | Begin development of simplified, computationally efficient models of the final scenario classes | 1/91 |
| K | Complete screening to identify final release scenario classes | 1/92 |

| Major event | Event description | Date |
|---|---|---|
| L | Draft report available to DOE on efficient models to be used in the total system simulations | 3/92 |
| M | Complete development/validation of performance assessment codes | 12/93 |
| N | Draft report available to DOE on the refined source term model | 6/92 |
| O | Complete interim probabilistic analysis of performance of the total system | 7/93 |
| P | Updated total system performance assessment calculations available | 5/94 |

Individual protection (Issue 1.2, Section 8.3.5.14)

Summary schedule information for Issue 1.2 is presented in Figure 8.5-24. The activities planned to support resolution of this issue address the EPA requirements limiting the annual dose equivalent from the repository system to any member of the public in the accessible environment following permanent closure. Two transport mechanisms must be considered at the Yucca Mountain site: ground-water transport and gas-phase transport. The activities planned under this issue will determine if any exposure to the public during the 1,000-yr period following permanent closure will meet the limits imposed by the EPA.

The major events shown on the schedule in Figure 8.5-24 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft of preliminary report on the evaluation of radionuclide releases and public doses via water and gas pathways available to DOE | 8/90 |
| B | Update available to DOE on the evaluation of radionuclide releases and public doses via water and gas pathways | 1/93 |
| C | Draft of final report on the evaluation of radionuclide releases and public doses via water and gas pathways available to DOE | 10/93 |

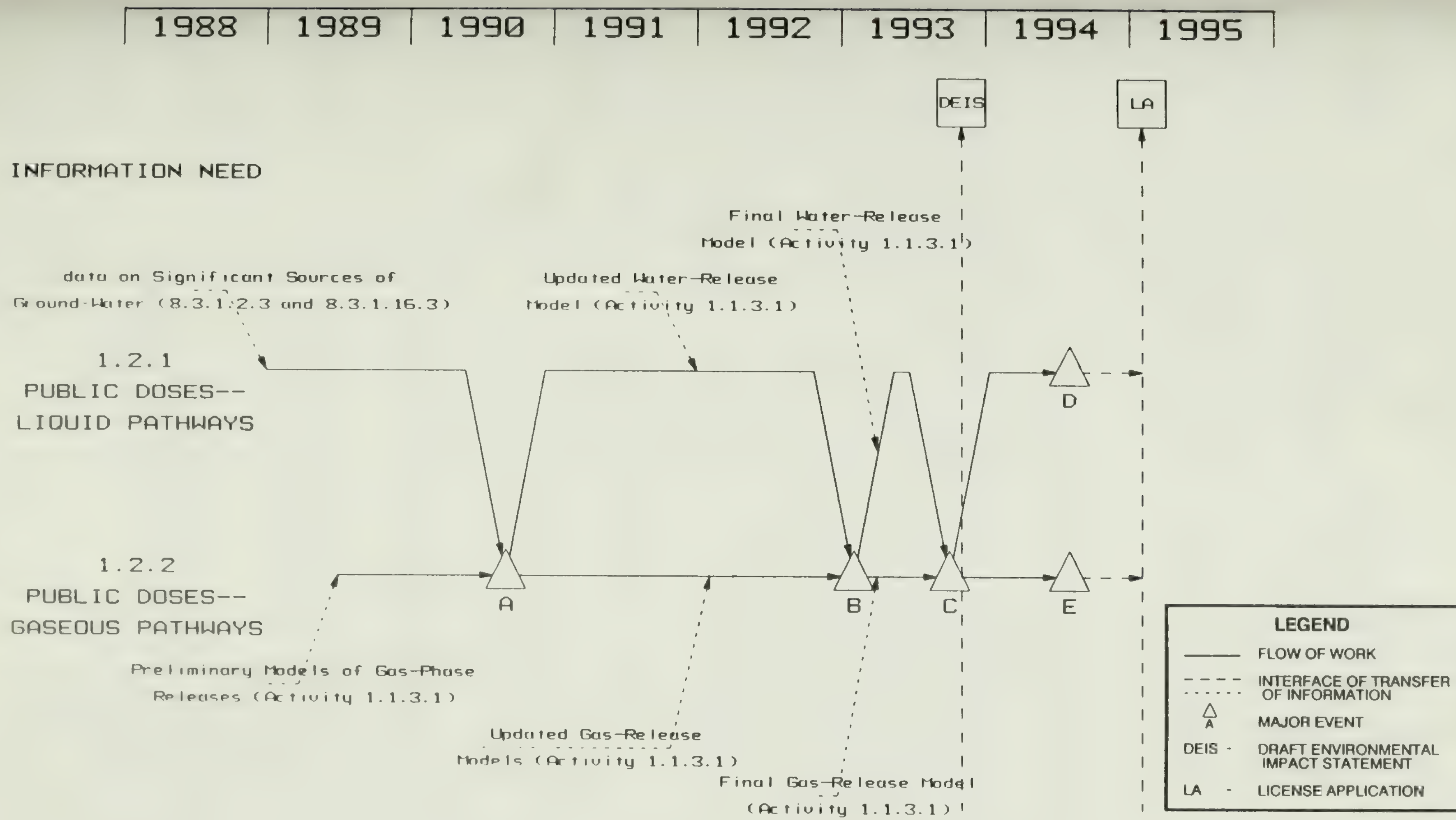


**Figure 8.5-24.** Summary schedule information for the Issue 1 2 (individual protection) This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| D | Report available to DOE on the evaluation of doses to the public through water releases | 7/94 |
| E | Report available to DOE on the evaluation of doses to the public through gas-phase releases | 7/94 |

Ground-water protection (Issue 1.3, Section 8.3.5.15)

Summary schedule information for Issue 1.3 is presented in Figure 8.5-25. The activities planned to support resolution of this issue are those necessary to determine if the concentrations of radioactive waste products in special sources of ground-water will meet the limits specified in 40 CFR 191.16. To comply with this requirement, the DOE will determine if special sources of ground water exist in the vicinity of the site. If special sources of ground water are found to be present, the DOE will then determine if the concentrations of radionuclides in any ground-water sources during the first 1,000 yr after disposal will meet the limits.

The major events shown on the schedule in Figure 8.5-25 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to DOE on the evaluation of the potential for special sources of ground-water at Yucca Mountain | 1/91 |
| B | Complete evaluation of the potential for special sources of ground-water at Yucca Mountain | 6/91 |
| C | Interim report available to DOE on the concentration of waste products in special sources of ground-water at Yucca Mountain | 4/93 |
| D | Final report on the concentration of waste products in special sources of ground-water at Yucca Mountain available to DOE | 3/94 |

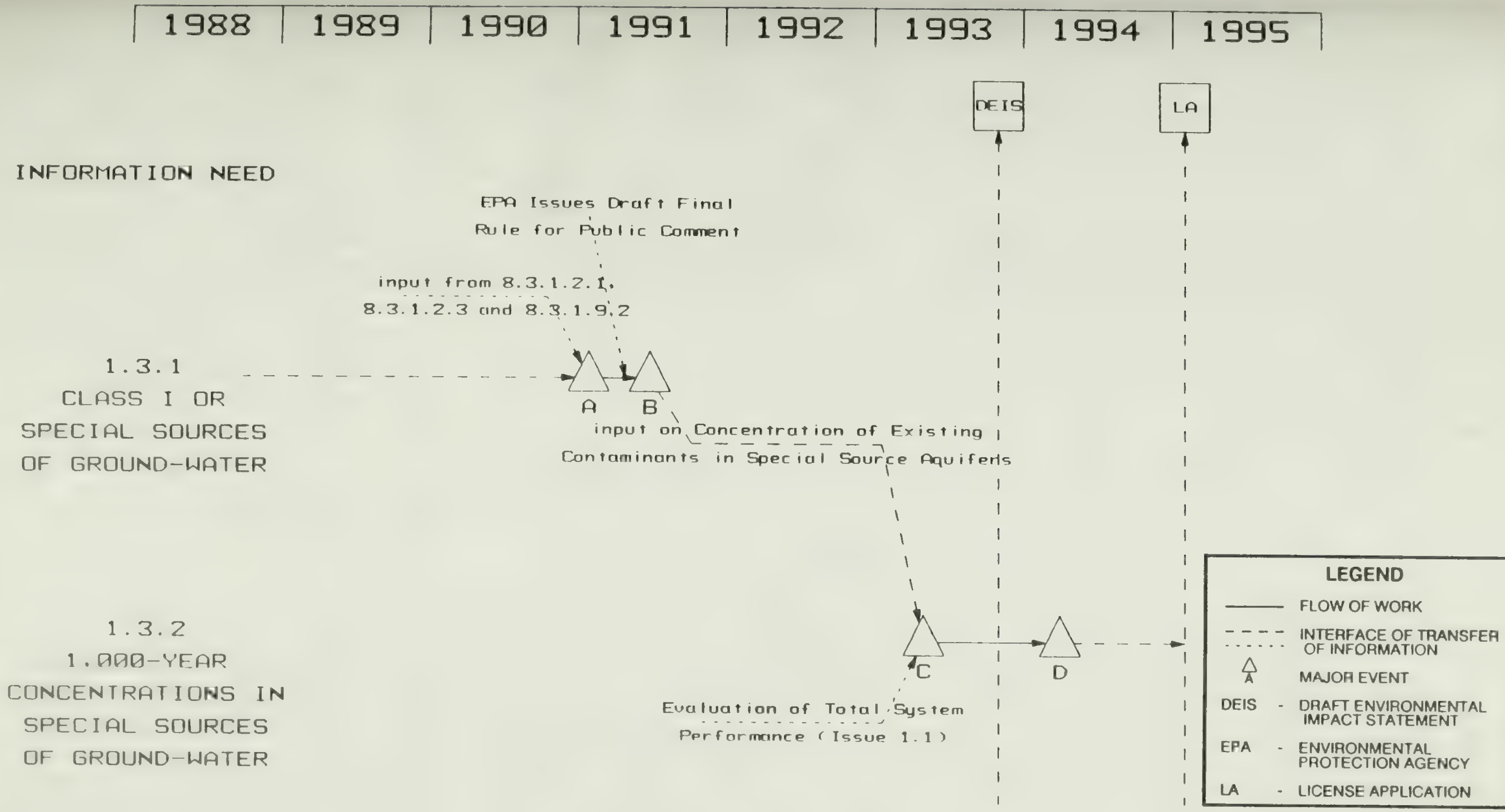


**Figure 8.5-25.** Summary schedule information for the Issue 1.3 (ground-water protection). This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

## 8.5.3 REPOSITORY DESIGN ACTIVITIES AND MILESTONES

The repository design must address regulatory requirements for both the preclosure and postclosure periods. The design must ensure radiological safety, as described in Section 8.5.2.1. For the preclosure period, 10 CFR 60.131-133 specify general design criteria for the geologic repository operations area and additional design criteria for the surface and underground facilities. A DOE requirement (10 CFR Part 960) also specifies that the designs should be feasible on the basis of reasonably available technology. For postclosure, a general criterion for the underground facility requires that the orientation, geometry, layout and depth of the facility, and the design of engineered barriers should contribute to the containment and isolation of radionuclides (10 CFR 60.133(a)(1)). The engineered barriers are also to be designed to assist the geologic setting in meeting the performance objectives. Other postclosure requirements on the repository design specify that it must allow the performance objectives to be met under the predicted postclosure conditions (10 CFR 60.133(h)). Another postclosure requirement placed on the geologic repository operations area, and combined with the repository design schedules for purposes of this section, is the requirement for the development of seals for shafts and boreholes (10 CFR 60.134).

Summary schedules for each preclosure and postclosure repository design issue presented in Sections 8.3.2.2 through 8.3.2.5 and the seal design issue presented in Section 8.3.3.2 are provided in this section. Information needs are represented as appropriate. The information need number and brief description are shown as well as major events associated with each information need. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. It should be noted that preliminary data meeting applicable quality assurance requirements (Section 8.6) will be available prior to report availability. Solid lines on the schedules represent information need durations and dashed lines show interfaces among information needs, as well as data transferred into or out of the issue. The schedules assume continuous integration among activities with only major ties shown.

<u>Configuration of underground facilities (postclosure) (Issue 1.11, Section 8.3.2.2)</u>

Summary schedule information for Issue 1.11 is presented in Figure 8.5-26. The activities planned to support resolution of this issue are those related to aspects of the underground facility design that have implications for the postclosure behavior of the repository. The requirements addressed by the issue state that the underground facility and the engineered barrier system shall contribute to the containment and isolation of radionuclides, incorporate sufficient flexibility to accommodate site specific conditions, and assist the geologic setting in meeting the postclosure performance objectives. Major considerations in addressing the requirements covered by this issue include the potential excavation effects on performance, the rock response to the thermal loads induced by the emplaced waste, and the availability of adequate usable host rock for the underground facility. Data from site programs are required for resolution of this issue,

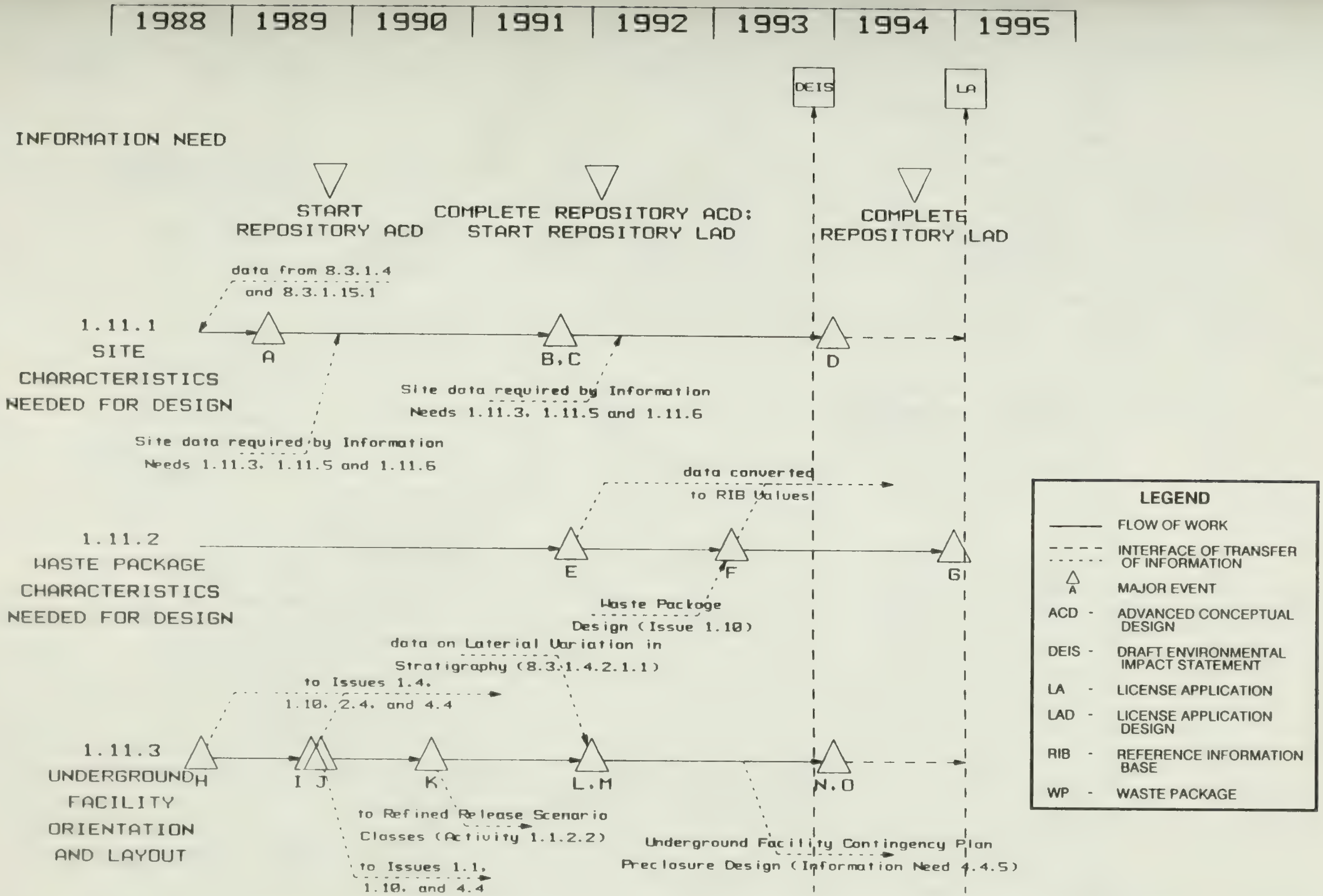


**Figure 8.5-26.** Summary schedule information for the Issue 1.11 (configuration of underground facilities - postclosure). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 3)

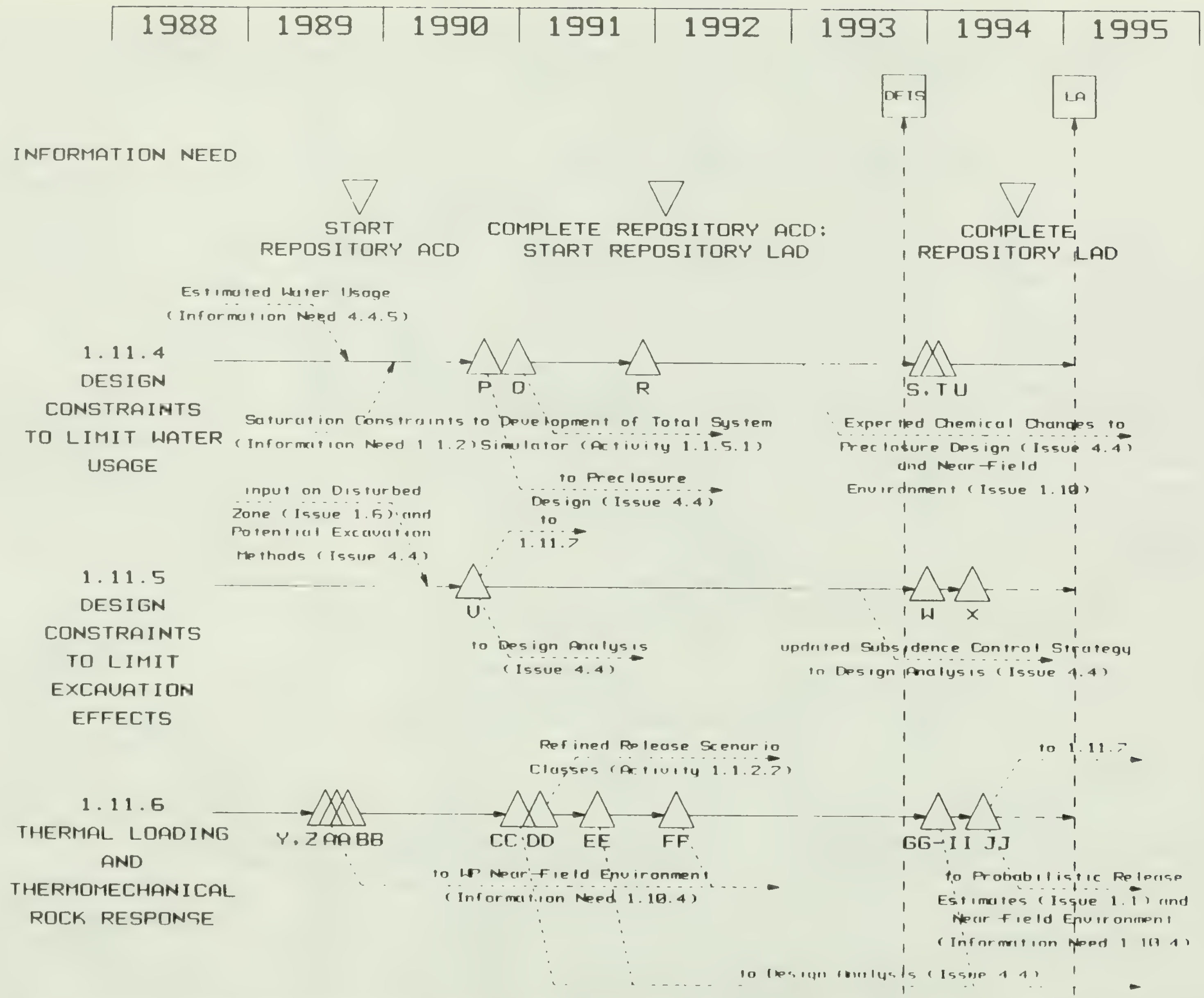


**Figure 8.5-26.** Summary schedule information for the Issue 1.11 (configuration of underground facilities postclosure) This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available (page 2 of 3)

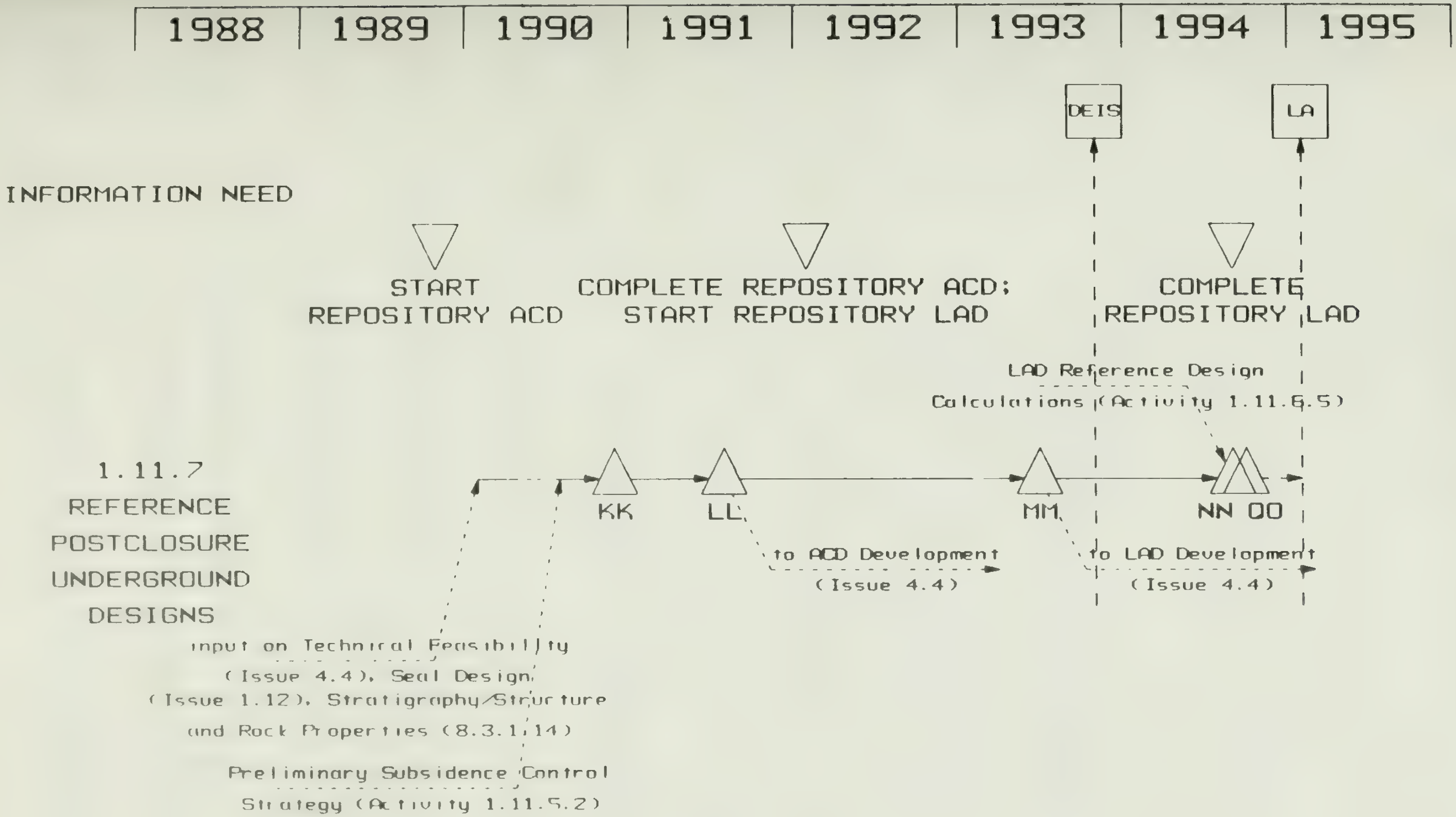


**Figure 8.5-26.** Summary schedule information for the Issue 1.11 (configuration of underground facilities - postclosure). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 3 of 3)

including information on stratigraphy and structure and on the thermal and mechanical properties of the host rock.

The major events shown on the schedule in Figure 8.5-26 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Draft report available to the DOE on the reference thermal/mechanical stratigraphy for advanced conceptual design (ACD) | 4/89 |
| B | Draft report available to DOE describing the reference thermal/mechanical stratigraphy of Yucca Mountain for license application design (LAD) | 9/91 |
| C | Draft report available to DOE documenting updated reference thermal/mechanical properties for LAD | 9/91 |
| D | Draft of final report on thermal/mechanical stratigraphy available to DOE | 12/93 |
| E | Complete determination and compilation of waste package information required for underground facility design | 1/92 |
| F | Updated information on waste package characteristics available for the reference information base | 5/93 |
| G | Final report on compilation of waste package information available to DOE | 3/94 |
| H | Complete preliminary performance comparison of vertical and horizontal emplacement of the waste packages | 10/88 |
| I | Underground facility moisture control plan available to DOE | 8/89 |
| J | Select waste-package emplacement orientation | 9/89 |
| K | Underground facility contingency plan available to DOE | 8/90 |
| L | Complete determination of area needed | 12/91 |

| Major event | Event description | Date |
|---|---|---|
| M | Complete evaluation of usable area and flexibility for LAD | 12/91 |
| N | Draft of final report on the underground facility moisture control plan available to DOE | 12/93 |
| O | Draft of final report on the underground facility contingency plan available to DOE | 12/93 |
| P | Draft report available to DOE on water usage criteria | 9/90 |
| Q | Complete development of preliminary underground facility material inventory criteria | 12/90 |
| R | Draft report available to DOE on expected chemical changes resulting from the use of construction materials | 11/91 |
| S | Draft of final report on chemical changes from construction materials available to DOE | 12/93 |
| T | Draft of final report on water management criteria available to DOE | 12/93 |
| U | Final report on material inventory criteria available to DOE | 1/94 |
| V | Preliminary subsidence control strategy available | 8/90 |
| W | Draft of final report on excavation methods criteria available to DOE | 12/93 |
| X | Final report on long-term subsidence control strategy available to DOE | 4/94 |
| Y | Draft report available to DOE on the borehole spacing strategy for ACD | 7/89 |
| Z | Complete strategy for underground facility design considerations to enhance containment | 7/89 |
| AA | Complete determination of allowable far-field areal power density for ACD | 8/89 |

| Major event | Event description | Date |
|---|---|---|
| BB | Draft report available to DOE on equivalent energy density concept for ACD | 9/89 |
| CC | Complete repository ACD near-field and thermomechanical analysis sensitivity studies | 12/90 |
| DD | Complete determination of allowable far-field areal power density for LAD | 2/91 |
| EE | Complete ACD near-field and far-field reference design analysis calculations | 7/91 |
| FF | Draft reports available to DOE on updated equivalent energy density concept and borehole spacing strategy for LAD | 2/92 |
| GG | Final report on equivalent energy concept available to DOE | 1/94 |
| HH | Complete LAD near-field and far-field thermomechanical analysis sensitivity study | 1/94 |
| II | Complete update of strategy and begin final report on underground facility design considerations to enhance containment | 1/94 |
| JJ | Complete LAD reference design calculations | 5/94 |
| KK | Complete reference postclosure design for ACD | 11/90 |
| LL | Complete reference ACD postclosure design confirmation | 7/91 |
| MM | Draft design analysis report available to DOE on performance assessment of LAD | 6/93 |
| NN | Design analysis report to support the license application available to DOE | 8/94 |
| OO | Complete reference LAD postclosure design confirmation | 9/94 |

Repository design criteria for radiological safety (Issue 2.7, Section 8.3.2.3)

Summary schedule information for Issue 2.7 is presented in Figure 8.5-27. The activities performed under this issue will provide radiological safety design analyses to support resolution of Issue 4.4

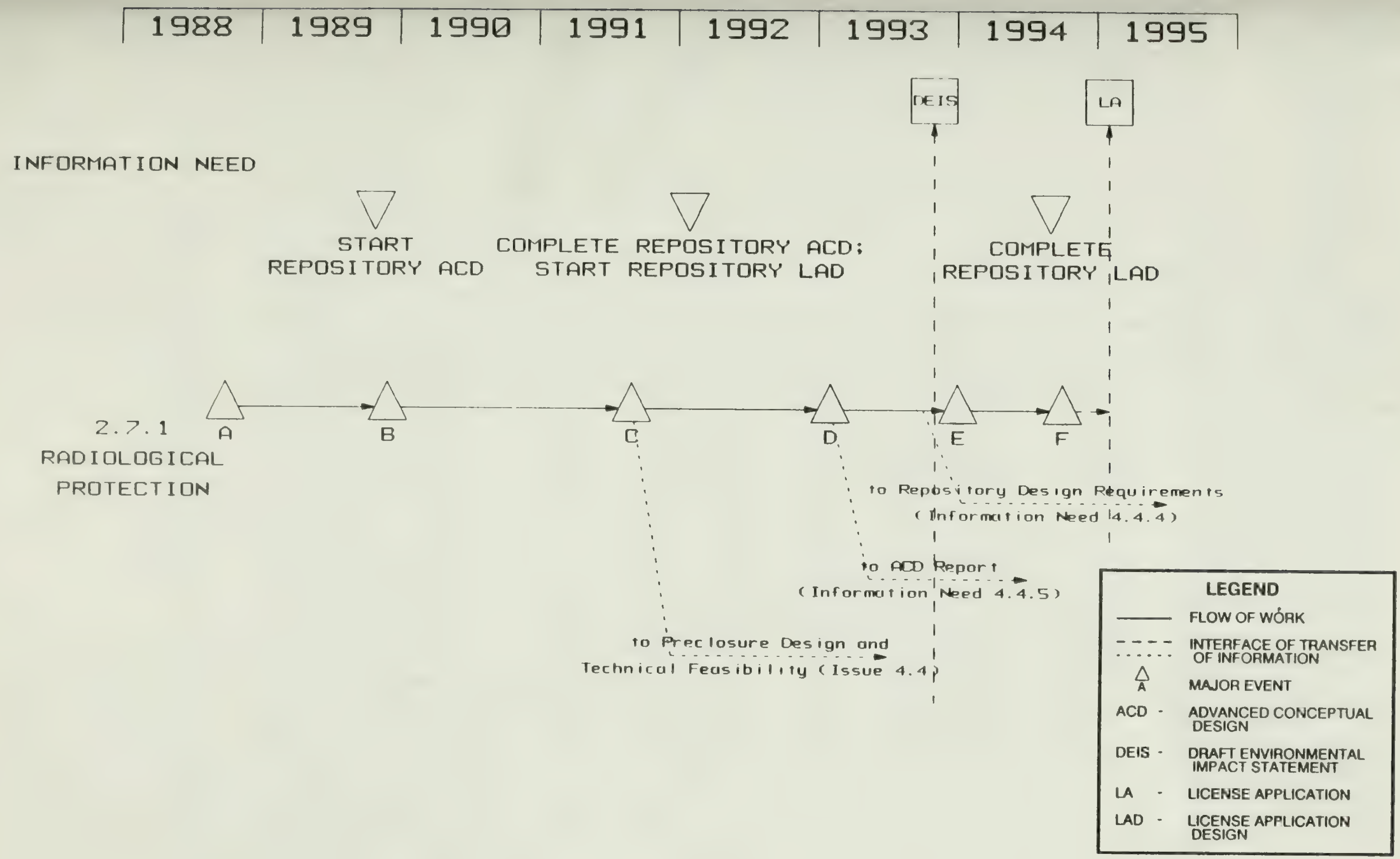


**Figure 8.5-27.** Summary schedule information for the Issue 2.7 (repository design criteria for radiological safety). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

(preclosure design and technical feasibility). Data from a variety of site programs, such as meteorology (Section 8.3.1.12) and preclosure tectonics (8.3.1.17) will be used to determine the site-specific conditions that must be considered in designing a repository facility that will protect the health and safety of repository workers and the public.

The major events shown on the schedule in Figure 8.5-27 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Continue generation of radiological safety requirements | 10/88 |
| B | Radiological requirements identified feed to advanced conceptual design (ACD) repository design requirements; continue to generate radiological requirements | 11/89 |
| C | Initiate preclosure risk assessment methodology (PRAM) analysis of ACD | 12/90 |
| D | Draft report available to the DOE on the results of PRAM analysis of ACD | 1/93 |
| E | Start preparation of report on PRAM analysis of license application design (LAD) | 12/93 |
| F | Report available to DOE on the results of PRAM analysis of LAD | 7/94 |

Nonradiological health and safety (Issue 4.2, Section 8.3.2.4)

Summary schedule information for Issue 4.2 is presented in Figure 8.5-28. The activities planned to support resolution of this issue are those necessary to demonstrate that repository designs and operating procedures will protect the nonradiological health and safety of repository workers. General areas of concern for nonradiological health and safety include stability of drifts and boreholes, adequate ventilation, and temperatures in the underground facility.

The major events shown on the schedule in Figure 8.5-28 and their planned dates of completion are provided in the following table:

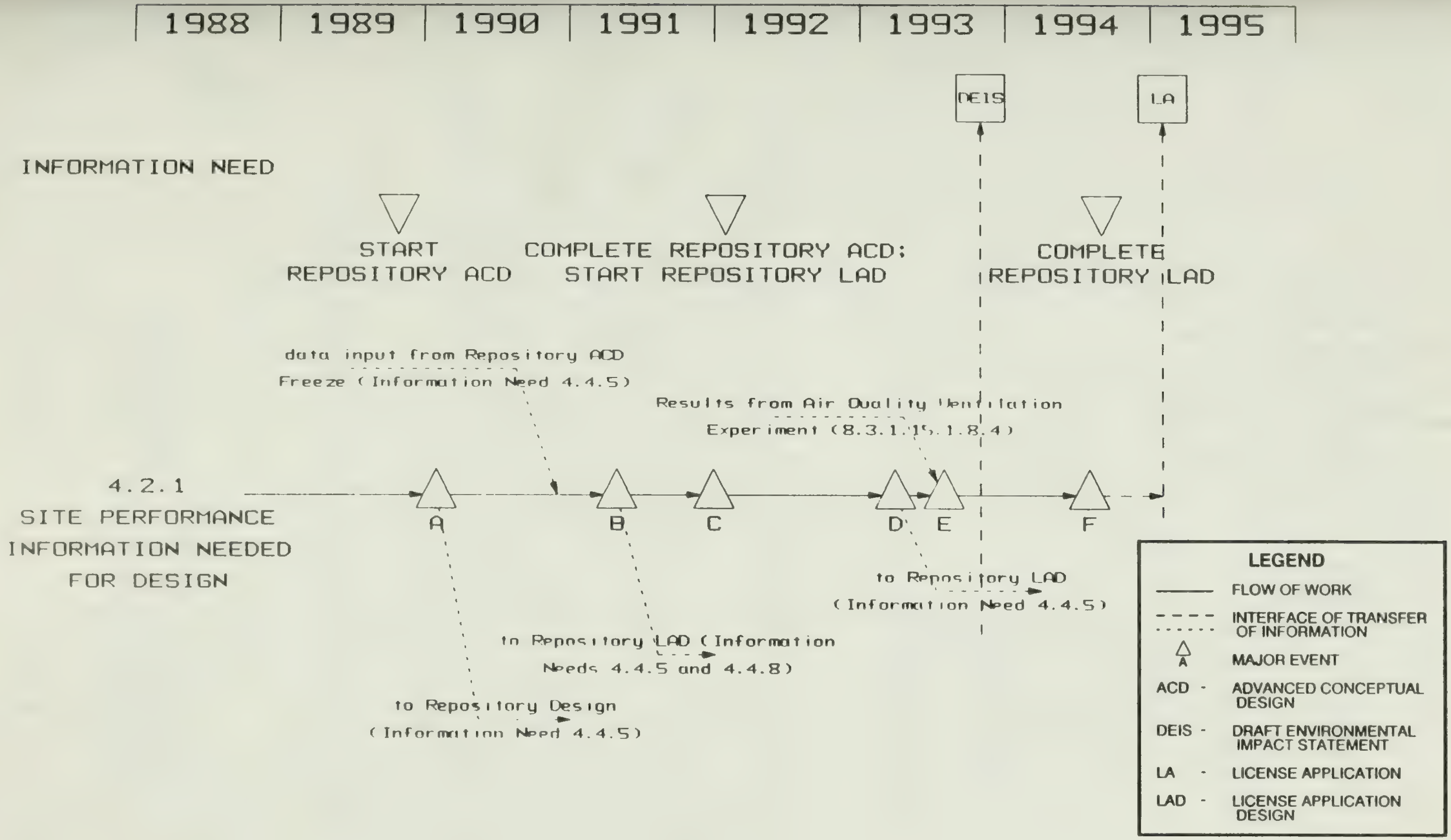


**Figure 8.5-28.** Summary schedule information for the Issue 4.2 (nonradiological health and safety). This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available.

| Major event | Event description | Date |
|---|---|---|
| A | Data on air quality and ventilation activities output to license application design (LAD) | 1/90 |
| B | Data on air quality and ventilation activities output to surface facility LAD | 4/91 |
| C | Data on access and drift usability studies output to LAD | 12/91 |
| D | Data on access and drift usability output to surface facility LAD | 3/93 |
| E | Complete design of activities to verify air quality and design | 7/93 |
| F | Complete studies to verify access and drift usability | 7/94 |

Preclosure design and technical feasibility (Issue 4.4, Section 8.3.2.5)

Summary schedule information for Issue 4.4 is presented in Figure 8.5-29. The activities supporting resolution of this issue are those necessary to demonstrate that the repository can be designed, constructed, operated, and closed using reasonably available or proven technology. This issue is also the focus for repository design requirements addressed under other issues. Because of this role, the activities performed under this issue must address a variety of design requirements, such as the ability to retrieve the waste, the quantities and types of waste to be emplaced, the waste package designs, the waste handling and emplacement systems, the stability of boreholes, the seismic design of surface facilities, and the mine ventilation systems. Activities under this issue will provide updated designs that meet design criteria, taking into account the various requirements placed on the preclosure repository facilities.

The major events shown on the schedule in Figure 8.5-29 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Complete updating repository design parameters (site data) for advanced conceptual design (ACD) freeze | 12/90 |

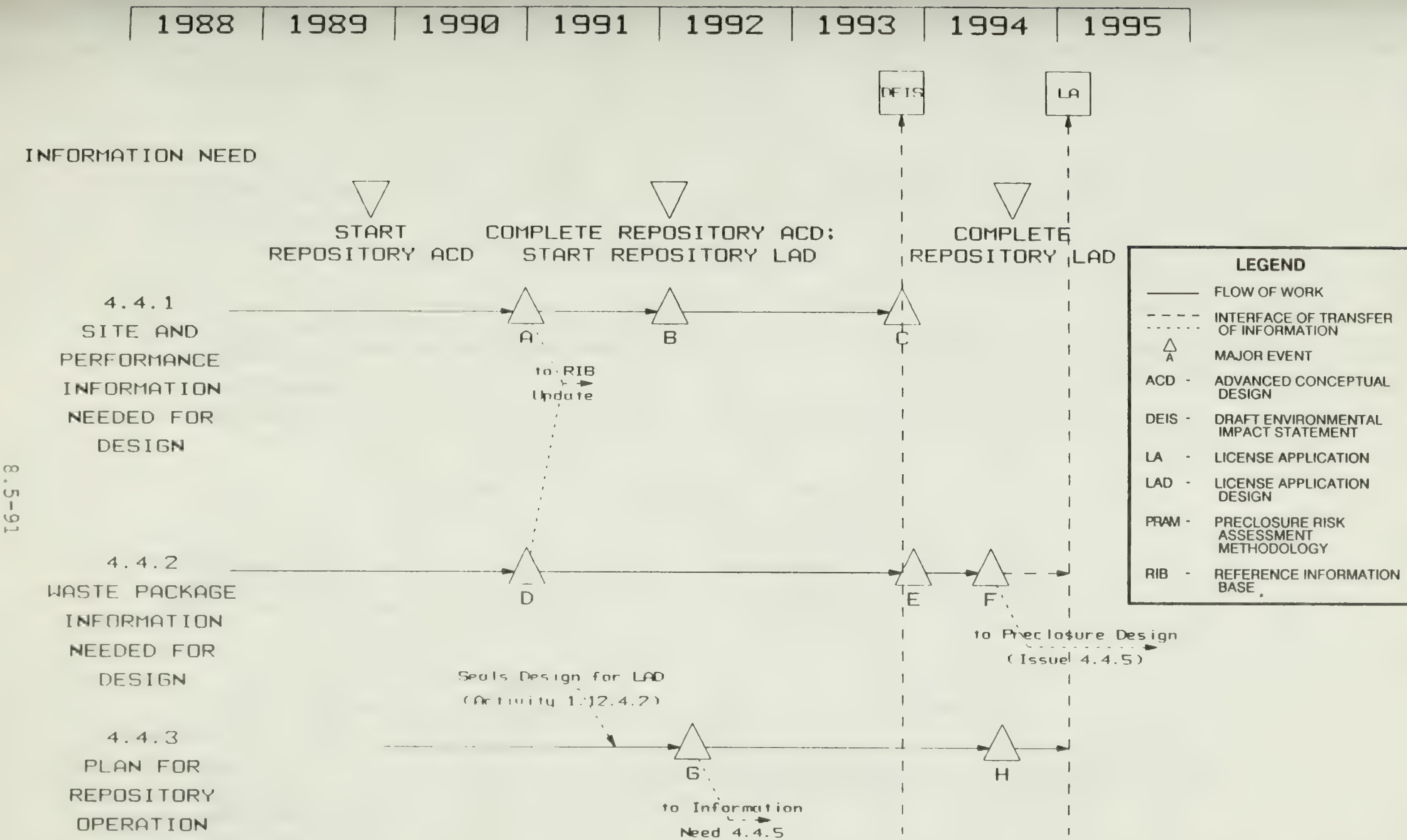


**Figure 8.5-29.** Summary schedule information for the Issue 4.4 (preclosure design and technical feasibility). This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 1 of 3)

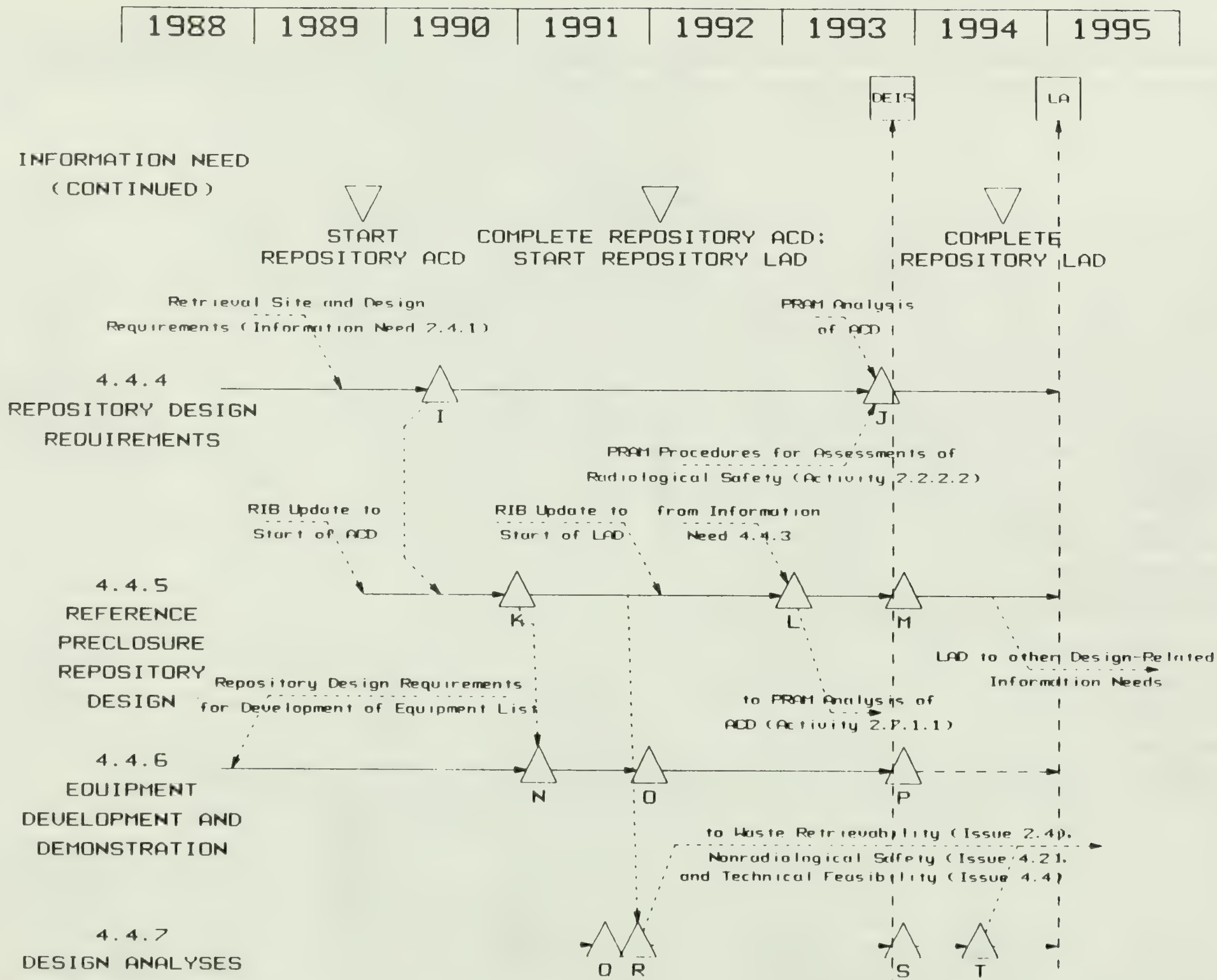


**Figure 8.5-29.** Summary schedule information for the Issue 4 4 (preclosure design and technical feasibility) This network is consistent with the Draft Mission Plan Amendment (DOE 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 2 of 3)

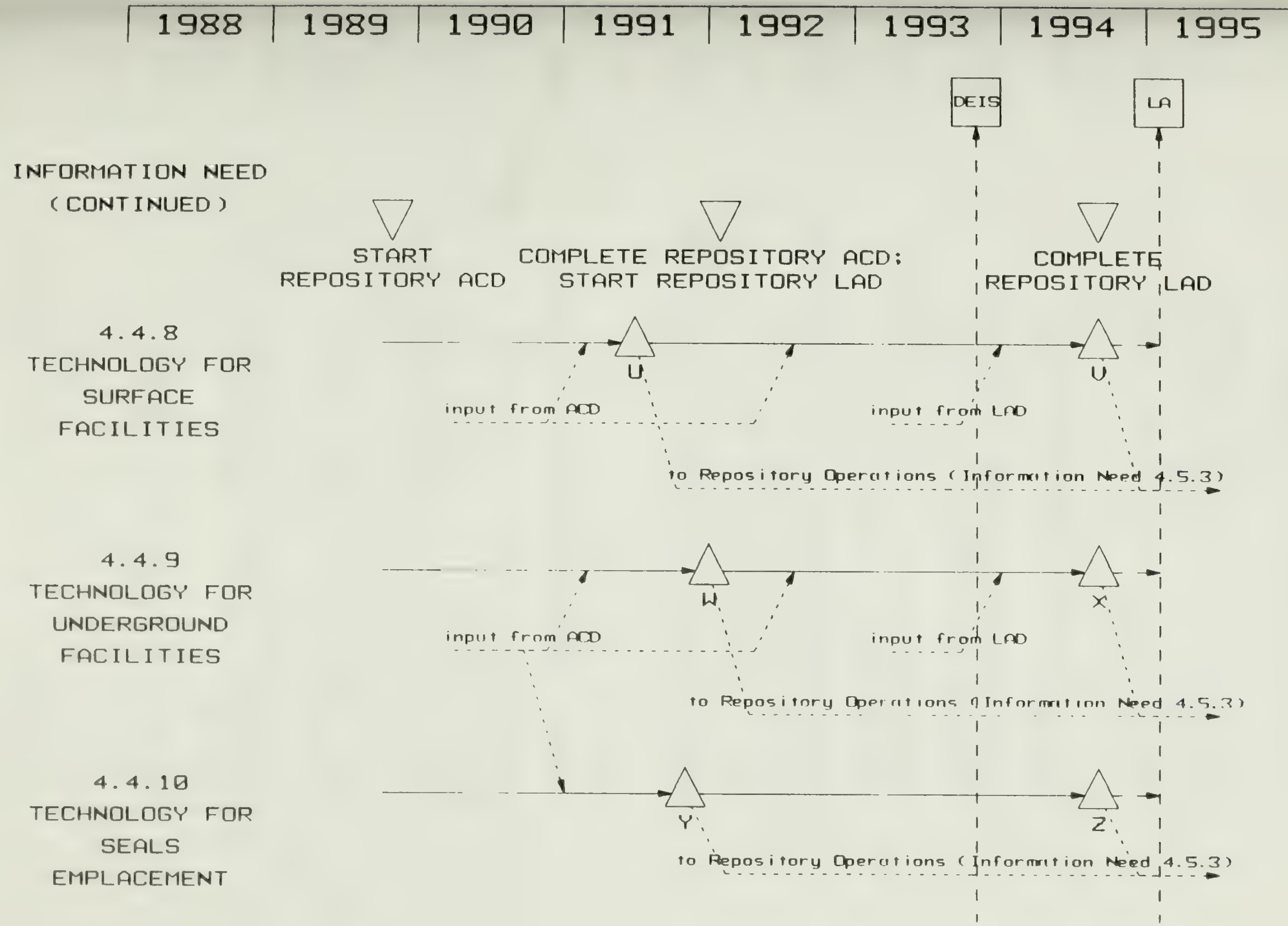


**Figure 8.5-29.** Summary schedule information for the Issue 4.4 (preclosure design and technical feasibility). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule. Revisions will be published in semiannual site characterization progress reports as new information becomes available. (page 3 of 3)

| Major event | Event description | Date |
|---|---|---|
| B | Complete updating of repository design parameters (site data) for start of license application design (LAD) | 1/92 |
| C | Complete updating of repository design parameters (site data) for LAD | 10/93 |
| D | Waste package/repository design interface at ACD freeze | 12/90 |
| E | Waste package/repository interface at LAD freeze | 11/93 |
| F | Complete waste package/repository design interface documents for LA | 6/94 |
| G | Repository operations plan for ACD available for ACD report | 3/92 |
| H | Repository operations plan for LAD available for LAD report | 6/94 |
| I | Complete repository design requirements for ACD | 5/90 |
| J | Update repository design requirements for LAD freeze | 9/93 |
| K | Repository ACD freeze | 12/90 |
| L | Complete repository ACD report | 1/93 |
| M | Repository LAD freeze | 11/93 |
| N | Complete detailed design of emplacement/ retrieval system hardware and emplacement/ retrieval equipment demonstration plan | 2/91 |
| O | Start conducting emplacement/retrieval equipment demonstrations | 12/91 |
| P | Complete documentation of emplacement/ retrieval equipment demonstration results for LA | 11/93 |
| Q | Complete design analyses of surface facilities for ACD | 8/91 |
| R | Draft reports available to DOE on repository access, opening, and borehole analyses for ACD and the design analysis of underground mine ventilation | 11/91 |

| Major event | Event description | Date |
|---|---|---|
| S | Complete surface facility design analysis for LAD | 11/93 |
| T | Complete updated design analysis | 6/94 |
| U | Complete evaluation of reasonably available technology for repository surface facilities for ACD | 6/91 |
| V | Report available to DOE on technology requirements for surface facilities for LAD | 8/94 |
| W | Complete evaluation of reasonably available technology for underground facilities for ACD | 12/91 |
| X | Report available to DOE on technology requirements for underground facilities for LAD | 8/94 |
| Y | Complete evaluation of reasonably available technology requirements for postclosure sealing design for ACD | 10/91 |
| Z | Report available to DOE on technology requirements for sealing design for LAD | 8/94 |

Seal characteristics (Issue 1.12, Section 8.3.3.2)

Summary schedule information for Issue 1.12 is presented in Figure 8.5-30. The activities planned to support resolution of this issue include those necessary to develop designs and evaluate performance of seals to be placed in the shafts, ramps, and boreholes associated with the development and closure of the repository. Data from a number of site programs, such as geohydrology (Section 8.3.1.2) and rock properties (Section 8.3.1.15), will be used to ensure that shafts and boreholes are adequately sealed so that after closure, they do not become pathways that compromise the ability of the geologic repository to meet the postclosure performance objectives. It should be noted that work under Information Need 1.12.2 (seal materials) will continue as confirmatory testing. The rationale for tests continuing as performance confirmation tests is provided in Section 8.3.5.6.

The major events shown on the schedule in Figure 8.5-30 and their planned dates of completion are provided in the following table:

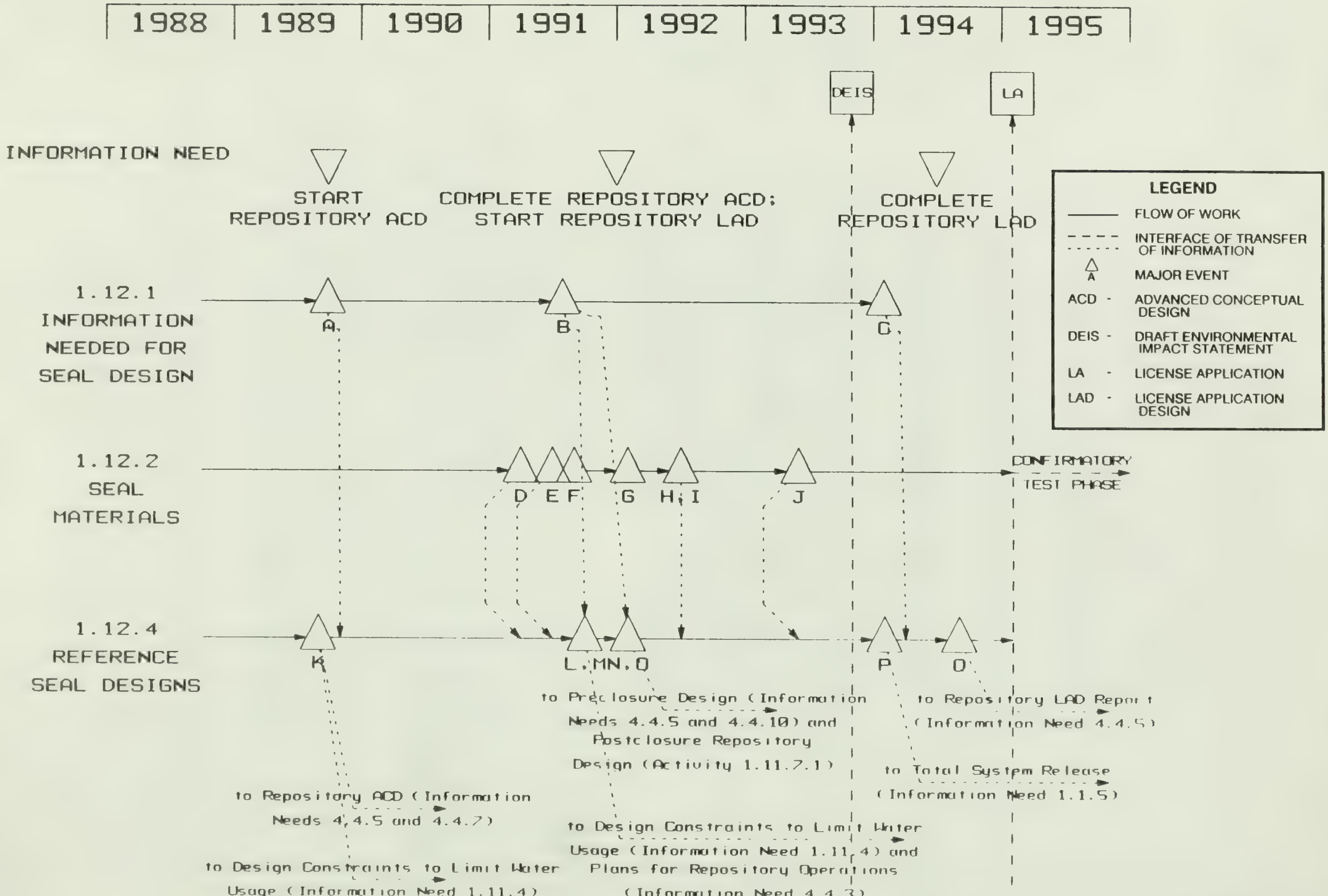


**Figure 8.5-30.** Summary schedule information for the Issue 1 12 (seal characteristics) This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| A | Complete compilation of preliminary list of information needed for seal design for advanced conceptual design (ACD); continue to compile information needed for seal design | 9/89 |
| B | Complete compilation of updated list of information needed for seal design for license application design (LAD) | 7/91 |
| C | Complete compilation of information used for seal design for license application | 1/94 |
| D | Complete Phase I material testing | 3/91 |
| E | Complete Phase II testing of seal material properties | 6/91 |
| F | Complete updates to degradation models for cementitious sealing materials | 8/91 |
| G | Draft report available to DOE on the results of Phase I testing | 1/92 |
| H | Draft report available to DOE on the results of Phase II testing of seal material properties | 6/92 |
| I | Draft report available to DOE on results of the crushed tuff properties test | 6/92 |
| J | Preliminary long-term test data available for last input to seal subsystem performance assessment; long-term testing continues | 5/93 |
| K | Complete update of sealing design requirements for ACD | 8/89 |
| L | Recommend final sealing materials for LAD | 9/91 |
| M | Complete seal design report for LAD | 9/91 |
| N | Complete ACD for sealing | 1/92 |
| O | Begin evaluation of reasonably available technology for sealing components | 1/92 |

| Major event | Event description | Date |
|---|---|---|
| P | Report available to DOE on seal subsystem performance assessment | 1/94 |
| Q | Incorporate results of the evaluation of reasonably available technology of sealing components into the LAD report | 8/94 |

## 8.5.4 WASTE PACKAGE DESIGN ACTIVITIES AND MILESTONES

The waste package design requirements address the preclosure and post-closure time periods in a manner similar to the repository design requirements covered by the milestones presented in Section 8.5.3. Detailed discussions of the waste package preclosure and postclosure design requirements are provided in Section 8.3.4. The primary requirements placed on the waste package for the preclosure time period cover such concerns as control of criticality, limits on reactive materials and free liquids, and the availability of production technologies for fabrication, closure, and inspection of the waste package.

For the postclosure time period, the waste package requirements address the need for considerations of potential interactions between the waste package and its environment that could compromise the function of the packages or the performance of the underground facility or the geologic setting.

Summary schedules for design-oriented waste package issues presented in Sections 8.3.4.2 through 8.3.4.4 are provided in this section. Summary schedule information related to waste package performance assessment issues was presented in Section 8.5.2. Information needs are represented as appropriate. The information need number and brief description are shown on the schedules , as well as major events associated with each information need. A major event, for purposes of these schedules, may represent the initiation or completion of an activity, completion or submittal of a report to the DOE, an important data feed, or a decision point. It should be noted that data meeting applicable quality assurance requirements (Section 8.6) will be available prior to report availability. Solid lines on the schedules represent information need durations and dashed lines show interfaces among information needs, as well as data transferred into or out of the issue. The schedules assume continuous integration among activities with only major ties shown.

### Waste package characteristics (postclosure) (Issue 1.10, Section 8.3.4.2)

Summary schedule information for Issue 1.10 is presented in Figure 8.5-31. The activities planned to support resolution of this issue are those required to demonstrate that interactions of the waste package with the emplacement environment do not compromise the function of the package or the

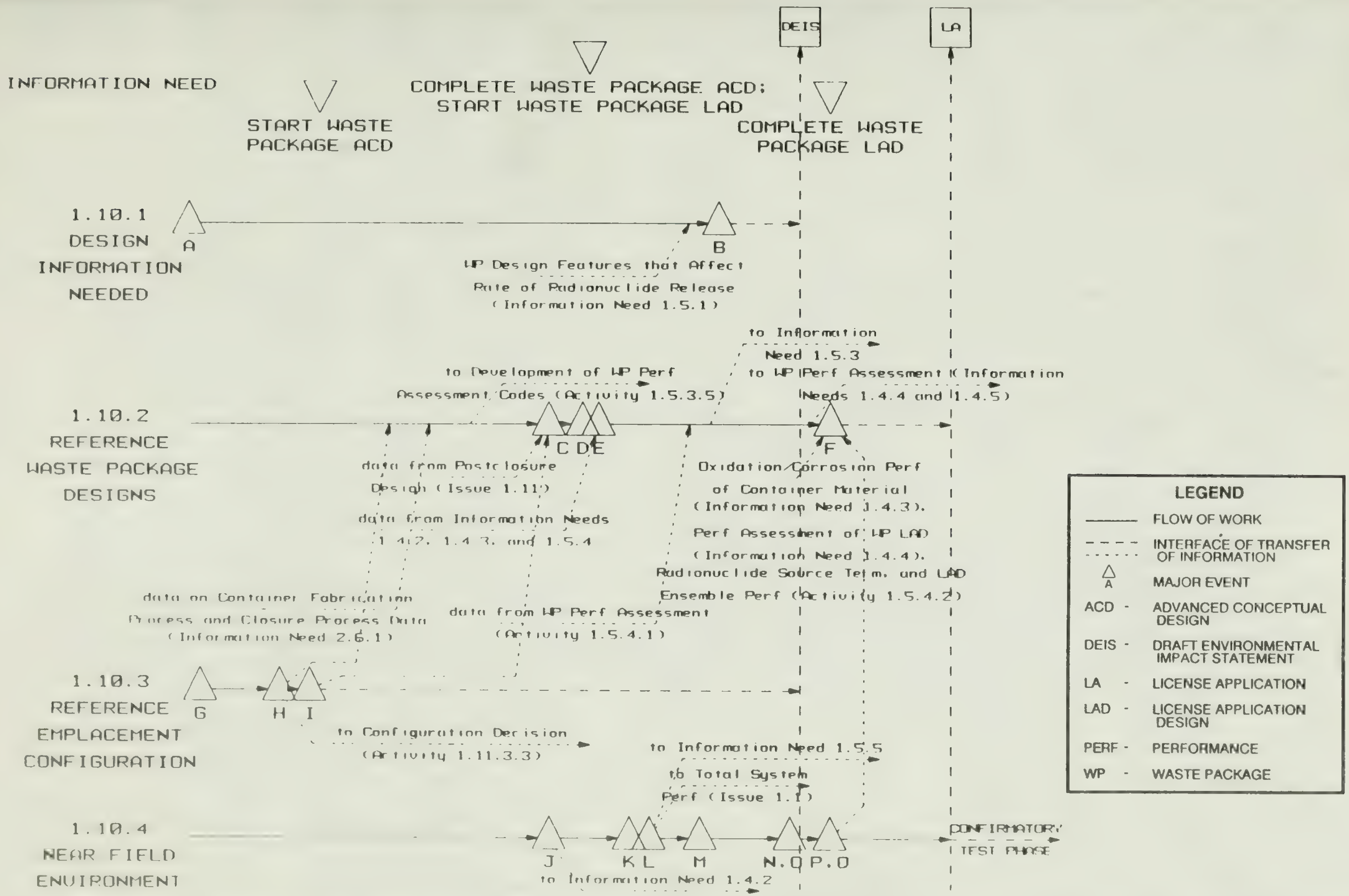


**Figure 8.5-31.** Summary schedule information for the Issue 1 10 (waste package characteristics postclosure). This network is consistent with the Draft Mission Plan Amendment (DOE, 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

performance of the underground facility or the geologic setting. The principal characteristics of high-level waste that must be considered are the high levels of radiation and the heat generated within the waste form. To understand the effects of the waste package on the emplacement environment, it is necessary, first, to understand ambient conditions at the repository horizon and the way those conditions will be altered by repository construction and operation. The activities displayed in this section are those necessary to show that the waste package design will meet the requirements addressed by this issue. It should be noted that some activities under Information Need 1.10.4 (near-field environment) will continue as confirmatory testing. The rationale for tests continuing as performance confirmation tests is provided in Section 8.3.5.16.

The major events shown on the schedule in Figure 8.5-31 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Continue development of test plans for long-term confirmation testing considering postclosure criteria | 10/88 |
| B | Complete development of test plans for long-term confirmation testing | 2/93 |
| C | Waste package advanced conceptual design (ACD) freeze | 9/91 |
| D | Complete waste package ACD; initiate waste package license application design (LAD) | 1/92 |
| E | Make final selection of material for barrier | 2/92 |
| F | Complete waste package LAD drawings and specifications | 1/94 |
| G | Continue waste-package emplacement-configuration studies | 10/88 |
| H | Information on waste package emplacement configurations available to Design Activity 1.11.3.3 (vertical and horizontal emplacement orientation decision) | 6/89 |
| I | Complete studies on reference waste-package emplacement configurations | 9/89 |
| J | Draft of final report on fracture flow studies available to DOE | 9/91 |

| Major event | Event description | Date |
|---|---|---|
| K | Begin waste-package environment test installation in the exploratory shaft | 5/92 |
| L | Final results of rock-water interactions using candidate repository horizon material available to DOE | 7/92 |
| M | Draft of final report on laboratory testing of waste-package environment hydrologic properties available to DOE | 12/92 |
| N | Draft of final report on the effects of grout, concrete, and other materials on waste package environment available to DOE; initiate document revisions to support the license application | 9/93 |
| O | Final report on waste package environment available to DOE | 9/93 |
| P | Final report on radionuclide source term available to DOE | 1/94 |
| Q | Complete evaluation of thermal stress on mechanical properties | 1/94 |

Waste package characteristics (preclosure) (Issue 2.6, Section 8.3.4.3)

Summary schedule information for Issue 2.6 is presented in Figure 8.5-32. The activities planned to support resolution of this issue are related to development of the waste package designs and the integration of the designs into the repository system. Requirements and constraints are placed on the waste form, the container, and the waste package assembly during the preclosure period. It is also important that the waste form and container are not subjected to conditions that could impact their performance during the postclosure period. The requirements derived through this issue are combined with those from the postclosure waste-package design issue (Issue 1.10, Section 8.3.4.2) to develop a consolidated design.

The major events shown on the schedule in Figure 8.5-32 and their planned dates of completion are provided in the following table:

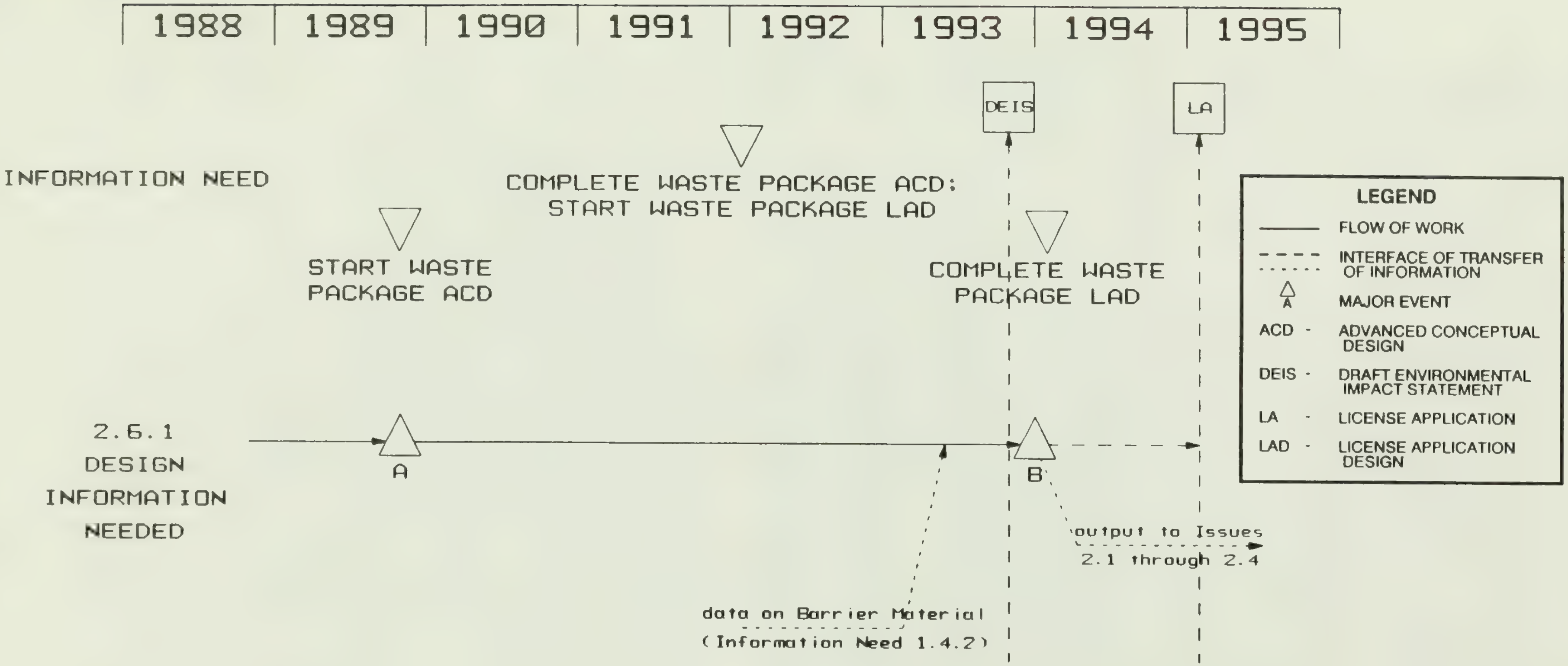


**Figure 8.5-32.** Summary schedule information for the Issue 2 6 (waste package characteristics · preclosure) This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| Major event | Event description | Date |
|---|---|---|
| A | Initiate development of preclosure waste package design requirements for ACD | 11/89 |
| B | Final report available to DOE on the development of preclosure waste package design requirements for LAD | 1/94 |

Waste package production technologies (Issue 4.3, Section 8.3.4.4)

Summary schedule information for Issue 4.3 is presented in Figure 8.5-33. The activities planned to support resolution of this issue are those related to the DOE requirements that the repository operations shall be demonstrated to be feasible on the basis of reasonably available technology. Rather than differentiate among various aspects of the production process, all production-related requirements are addressed in this issue. Activities to be performed under this issue include process criteria definition, process identifications, process testing and evaluation, and prototype fabrication and testing.

The major events shown on the schedule in Figure 8.5-33 and their planned dates of completion are provided in the following table:

| Major event | Event description | Date |
|---|---|---|
| A | Complete report on container closure process development | 11/90 |
| B | Complete report on waste-package closure inspection development | 11/90 |
| C | Complete report on container fabrication process development | 11/91 |
| D | Complete preparation of plans and procedures for waste-package closure inspection process for inclusion in report on waste-package prototype fabrication process | 6/92 |
| E | Begin preparation of reports, plans, and procedures for waste-package prototype fabrication process | 2/93 |
| F | Complete fabrication of waste package prototype; initiate demonstration tests of waste package prototype | 11/93 |

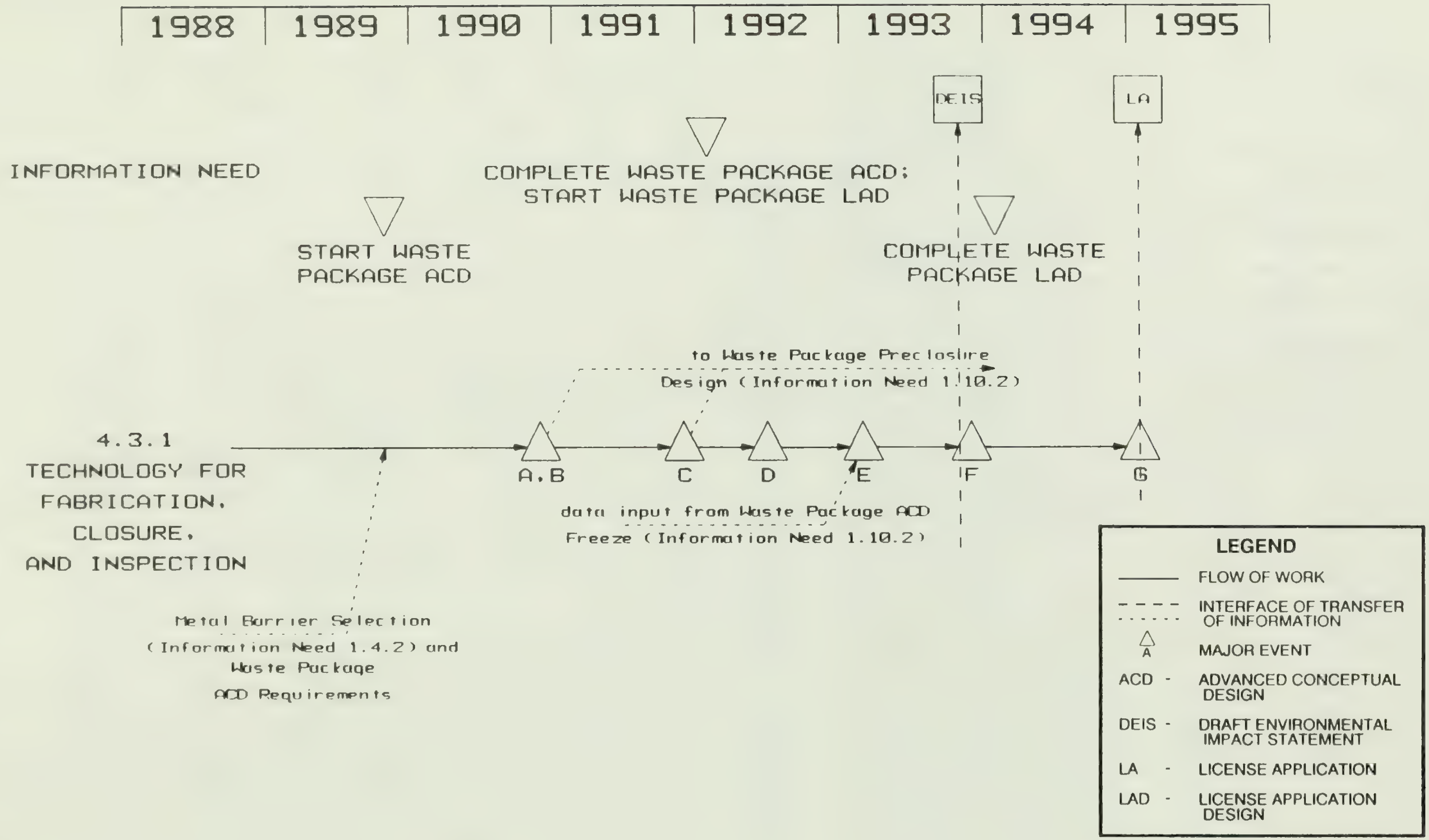


**Figure 8.5-33.** Summary schedule information for Issue 4 3 (waste package production technologies) This network is consistent with the Draft Mission Plan Amendment (DOE. 1988a) schedule Revisions will be published in semiannual site characterization progress reports as new information becomes available

| 4ajor ›vent | Event description | Date |
|---|---|---|
| G | Complete engineering tests of advanced conceptual design (ACD) prototype waste package | 1/95 |

## }.5.5 MAJOR DECISION POINTS FOR THE YUCCA MOUNTAIN PROJECT

This section presents the major decision points currently recognized by :he Yucca Mountain Project. A logic diagram, shown in Figure 8.5-34, .llustrates the interfaces among the major program elements affected by the lecisions.

The timing of the highest level decision points is closely tied to nilestones in the Mission Plan (DOE, 1985b). Decision points for the Yucca 4ountain Project are generally related to the provision of site information :equired by the performance and design elements to address licensing and )ther regulatory requirements. This information consists of the technical lata bases and supporting information that will allow an evaluation of compliance with regulatory requirements. Preliminary design and performance assessment analyses and calculations, such as those presented in the environmental assessment (DOE, 1986b), were completed on the basis of limited site information. If new site information collected during site characterization raises questions about earlier models and hypotheses, then certain design or performance strategies and approaches may require revision. Revised design or performance strategies may also result in the need for additional site information.

Some of the major decision points covered in this section do not rely on site information. Decision points may be determined by the activities of other Federal agencies, such as the publication of the site characterization analyses by the NRC. Other decision points will be reached by the systematic progress of design activities from preliminary conceptual to advanced conceptual design, and ultimately to the final design suitable for inclusion in the license application.

Table 8.5-3 lists major decision points in the site characterization program and describes their likely outcome. These deal with topics such as the need to extend the exploratory shaft (ES) into the Calico Hills unit (including the determination of impacts on waste isolation), and the need to expand ES drifting into the southern part of the repository block. Additionally, a range of geophysical testing techniques will be evaluated during site characterization and new tests planned as appropriate.

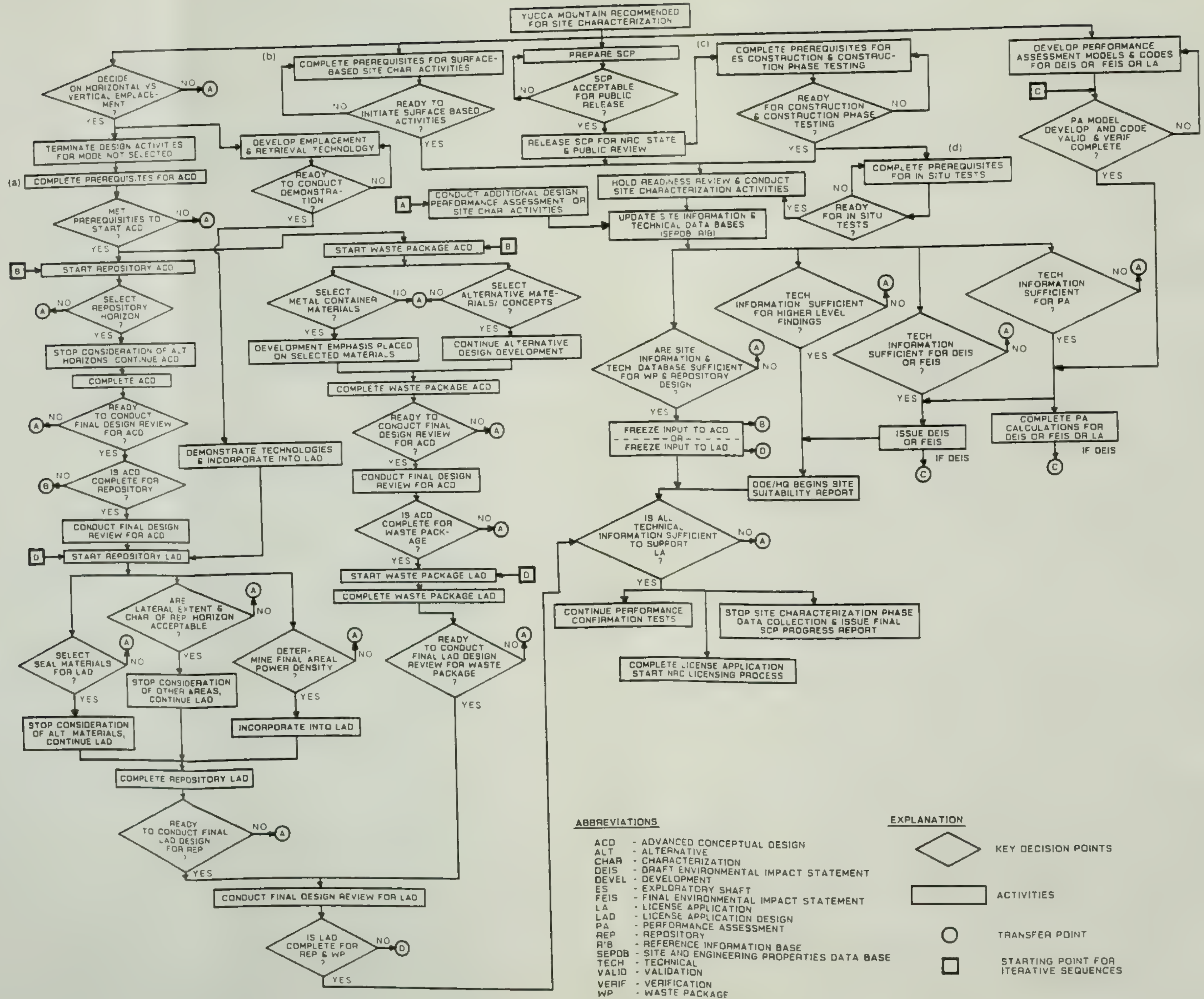


**Figure 8.5-34.** General logic diagram for major decision points in site characterization program

Table 8.5-3. Major decision points in the site characterization program

| Decision point | Likely outcome |
|---|---|
| Is the SCP acceptable for public release? | Release SCP for NRC, State, and public review |
| Can the decision be made on horizontal versus vertical waste emplacement? | Stop all design and analyses of emplacement mode not selected |
| Have all prerequisites been met to start advanced conceptual design (ACD)?[a] | Conduct waste package and repository ACD |
| Is Project prepared to initiate surface-based activities?[b] | Complete readiness review and begin surface-based activities |
| Is the Project ready for exploratory shaft (ES) construction and ES construction-phase testing?[c] | Complete readiness review and start ES construction and ES construction-phase testing |
| Can the metal barrier be selected for the waste package? | Primary emphasis placed on selected materials |
| Can the decision be made to use or not use a ceramic liner for waste packages? | Continue or terminate liner design and production |
| Can the repository horizon be selected? | Stop consideration of alternative horizons and continue ACD |
| Is the ACD adequate and complete? | Conduct final design review for ACD; complete all required design documents; start license application design (LAD) |
| Is the Project prepared to conduct ES in situ testing?[d] | Complete readiness review and start in situ testing |
| Can the decision on final areal power density be made? | Incorporate final areal power density into LAD |
| Is the lateral extent sufficient and are the characteristics of repository horizon acceptable? | Stop consideration of extension areas; continue LAD |
| Can the reference sealing material for LAD be selected? | Stop consideration of alternative materials; continue LAD |

Table 8.5-3. Major decision points in the site characterization program (continued)

| Decision point | Likely outcome |
|---|---|
| Is the Project prepared to conduct the demonstration of waste emplacement and retrieval technologies? | Demonstrate the technologies and incorporate into LAD |
| Are site information and the technical data base sufficient for waste package and repository design? | Freeze input to ACD; continue data collection for LAD<br>or<br>Freeze input to LAD |
| Is the Project ready to hold the final LAD design review for waste package? | Conduct the final LAD design review and activities for waste package design |
| Is the Project ready to hold the final LAD design review for repository? | Conduct the final LAD design review and terminate LAD activities for repository design |
| Are performance assessment model development and code validation and verification complete? | Complete performance assessment calculations for draft environmental impact statement (DEIS), final environmental impact statement (FEIS) or license application (LA) |
| Are site information and the technical data base sufficient for performance assessment calculations? | Complete performance assessment calculations for DEIS, FEIS, or LA |
| Is all technical information adequate to issue DEIS? | Issue DEIS |
| Is all technical information sufficient to support higher level findings on DOE siting guidelines? | DOE/HQ begins site suitability report |
| Is all technical information sufficient for LA? | Issue final SCP progress report supporting LA; complete LA; start NRC licensing process |

[a]Prerequisites for ACD:
- waste emplacement mode selection
- systems requirements document published
- repository design requirements document published
- waste package design requirements document published
- reference information base data available

Table 8.5-3. Major decision points in the site characterization program (continued)

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Footnotes (continued)

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- waste package postclosure compliance strategy developed

[b]Requirements for readiness review prior to initiation of surface-based activities:

- land access agreements in place
- applicable environmental permits obtained
- appropriate study plans provided to NRC
- test procedures and quality assurance (QA) level assignments completed and approved

[c]Requirements for ES construction and ES construction-phase testing readiness review:

- applicable environmental permits obtained
- construction-phase study plans provided to NRC
- test procedures and QA level assignments completed and approved

[d]Requirements for ES in situ testing readiness review:

- in situ phase study plans provided to NRC
- test procedures and QA level assignments completed and approved

## 8.5.6 SUMMARY SCHEDULE

The following sections provide information useful for developing an overall understanding of the structure of the site characterization program, together with the repository and waste package design and the performance assessment programs. The summary schedule presented in Section 8.5.6.1 portrays the evolution of the major elements of the program from the present time through the license application to the Nuclear Regulatory Commission (NRC). The major Draft Mission Plan Amendment (DOE, 1988) milestones and the scheduled completion date for each milestone are listed in Section 8.5.6.1. A schematic figure, presented in Section 8.5.6.2, and the text describing preliminary plans for regulatory and institutional activities and milestones provide an overview of the general approach that will be used to document the results of site characterization and important design and performance assessment products.

### 8.5.6.1 Presentation of summary schedule for the Yucca Mountain site

Figure 8.5-35 provides a summary schedule for the site characterization program planned at the Yucca Mountain site. The schedule should be viewed as an aid to understanding the overall structure of the site characterization program. A list of the major Draft Mission Plan Amendment milestones (DOE, 1988) and the scheduled completion date for these milestones is provided in the following table. These milestones are a subset of the major events shown on the summary schedule.

| Milestone | Current schedule |
|---|---|
| Start of exploratory shaft construction | Second quarter 1989 |
| Start of in situ test phase | Fourth quarter 1990 |
| Draft environmental impact statement (DEIS) | 1993 |
| Final environmental impact statement (FEIS) | 1994 |
| Submittal of the site recommendation report (SRR) to the President | 1994 |
| Submittal of the license application (LA) to the Nuclear Regulatory Commission | 1995 |

Other milestones shown on the summary schedule in Figure 8.5-35 are listed in the following table. The major program elements represented include regulatory and institutional (see Section 8.5.6.2), performance assessment, repository and waste package design, site investigations, and exploratory shaft.

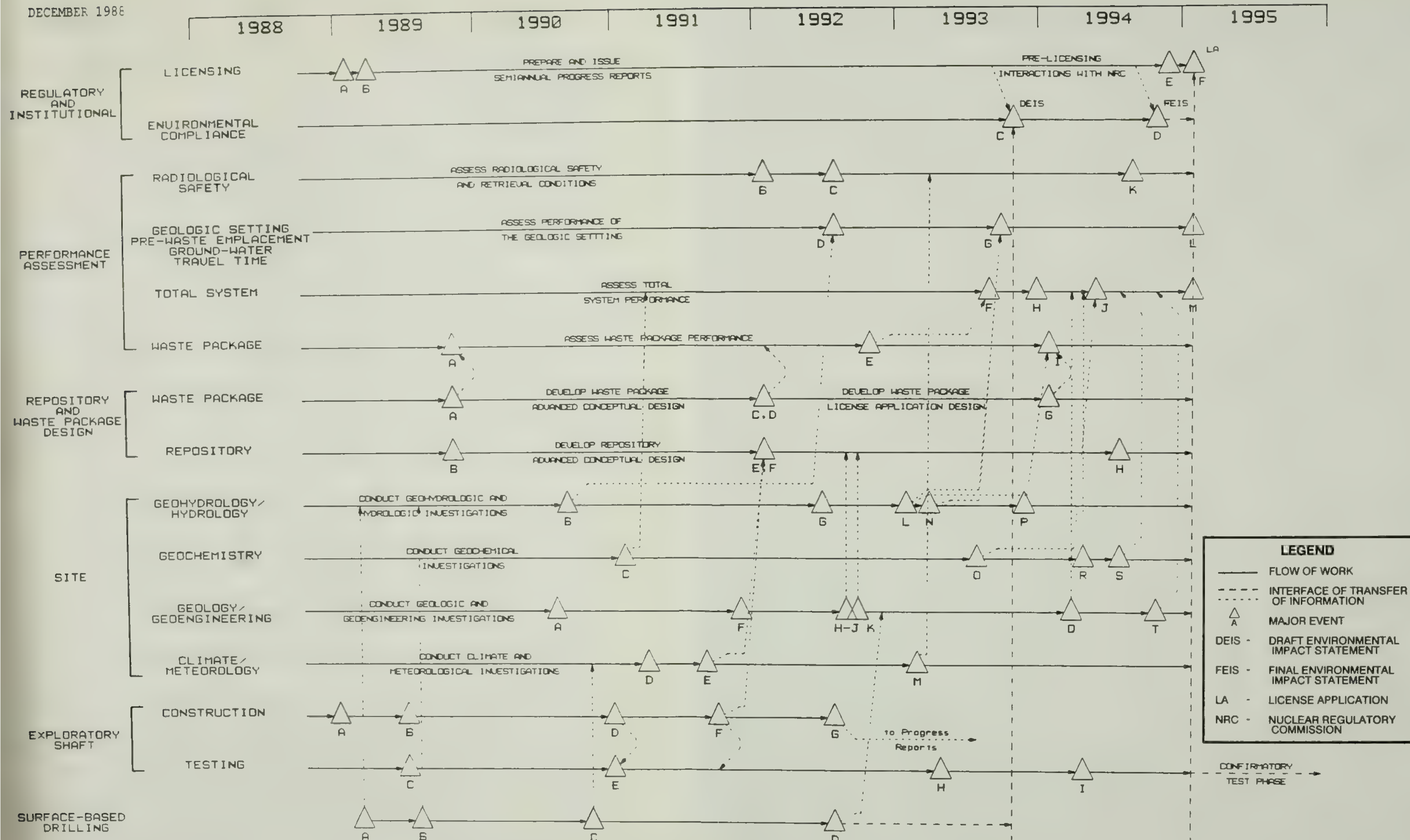


**Figure 8.5-35.** Summary schedule information for the site characterization program at Yucca Mountain

| Major event | Related SCP section | Event description | Date |
|---|---|---|---|
| | | REGULATORY AND INSTITUTIONAL MILESTONES | |
| A | NA[a] | DOE/HQ issues SCP to public | 12/88 |
| B | NA | Conduct public hearings on SCP | 3/89 |
| C | NA | Issue draft environmental impact statement (DEIS) | 10/93 |
| D | NA | Issue final environmental impact statement (FEIS) | 10/94 |
| E | NA | Submit site recommendation report (SRR) to the President | 11/94 |
| F | NA | Submit license application (LA) to the NRC | 1/95 |
| | | PERFORMANCE ASSESSMENT | |
| A | 8.3.5.9.2.1 | Metal barrier material selected | 10/89 |
| B | 8.3.5.2.6 | Complete retrieval compliance analysis required for advanced conceptual design (ACD) | 1/92 |
| C | 8.3.5.4.1 and 8.3.5.4.2 | Complete ACD assessment of radiological safety during normal operations | 7/92 |
| D | 8.3.5.12.4 | Preliminary calculations of pre-waste-emplacement ground-water travel time (GWTT) available for DEIS | 7/92 |
| E | 8.3.5.9.4 and 8.3.5.9.5 | Complete performance assessment of waste package ACD | 10/92 |
| F | 8.3.5.13.5 | Total system performance assessment calculations available for DEIS | 8/93 |
| G | 8.3.5.12.4 | Complete updating calculations of pre-waste-emplacement GWTT for FEIS and LA | 9/93 |
| H | 8.3.5.13.4 | Complete development/validation of performance assessment codes | 12/93 |
| I | 8.3.5.9.4 8.3.5.9.5 | Complete performance assessment of waste-package license application design (LAD) | 1/94 |

| Major event | Related SCP section | Event description | Date |
|---|---|---|---|
| | | PERFORMANCE ASSESSMENT (continued) | |
| J | 8.3.5.13.5 | Updated total system performance assessment calculations available | 5/94 |
| K | 8.3.5.4.1<br>8.3.5.4.2 | Complete LAD assessment of radiological safety during normal operations | 8/94 |
| L | 8.3.5.16 | Complete baseline phase and begin confirmation phase of performance confirmation | 1/95 |
| M | 8.3.5.10.3 | Complete documentation of the verification and validation of waste-package assessment codes | 1/95 |
| | | REPOSITORY AND WASTE PACKAGE DESIGN | |
| A | 8.3.4.2.2 | Start waste package ACD | 10/89 |
| B | 8.3.2.5.5 | Start repository ACD | 10/89 |
| C | 8.3.4.2.2 | Complete waste package ACD | 1/92 |
| D | 8.3.4.2.2 | Start waste package LAD | 1/92 |
| E | 8.3.2.5.5 | Complete repository ACD | 1/92 |
| F | 8.3.2.5.5 | Start repository LAD | 1/92 |
| G | 8.3.4.2.2 | Complete waste package LAD | 1/94 |
| H | 8.3.2.5.5 | Complete repository LAD | 7/94 |
| | | SITE | |
| A | 8.3.1.4.2.2 | Final report on geologic mapping of the Paintbrush Tuff available to DOE | 7/90 |
| B | 8.3.1.2.1.4 | Draft report available to DOE on the conceptual model of the saturated zone at Yucca Mountain | 8/90 |
| C | 8.3.1.3.7.1 | Update of geochemical/geophysical model available to DOE | 1/91 |

| Major event | Related SCP section | Event description | Date |
|---|---|---|---|
| D | 8.3.1.12.4.1 | Draft report available to DOE on extreme weather phenomena and expected recurrence intervals | 3/91 |
| E | 8.3.1.5.2.2 | Draft report summarizing modern flooding events available to DOE; report feeds report on predictions of future flooding and debris movement | 8/91 |
| F | 8.3.1.17.3.6 | Complete earthquake source evaluation | 11/91 |
| G | 8.3.1.16.2.1 | Draft report available to DOE on the effects of water withdrawals on the local flow system | 6/92 |
| H | 8.3.1.17.2.1 | Final reports on the potential for faulting at the surface facilities and for displacement on faults that intersect underground facilities | 8/92 |
| I | 8.3.1.4.2.3 | Draft report available to DOE on the preliminary site geologic description; report feeds development of three-dimensional geologic model | 8/92 |
| J | 8.3.1.9.2.1 | Final report on evaluation of natural resource potential at the site available to DOE | 8/92 |
| K | 8.3.1.17.4.12 | Preliminary regional tectonic model available to DOE | 9/92 |
| L | 8.3.1.2.2.9 | Draft report available to DOE on the preliminary evaluation of unsaturated zone hydrology | 1/93 |
| M | 8.3.1.12.2.1 | Draft of five-year summary report on meteorological conditions available to DOE | 2/93 |
| N | 8.3.1.2.2.3 | Preliminary report on the hydrologic properties of tuff matrix available to DOE | 3/93 |

| Major event | Related SCP section | Event description | Date |
|---|---|---|---|
| | | SITE (continued) | |
| O | 8.3.1.3.5.1 | Draft report available to DOE on solubility measurements | 7/93 |
| P | 8.3.1.2.3.3 | Report available to DOE on the preliminary description of the saturated zone | 11/93 |
| Q | 8.3.1.8.3.1 | Report available to DOE on the assessment of the effects of faulting on flux rates | 3/94 |
| R | 8.3.1.3.7.1 | Final report on the results of retardation sensitivity analysis available to DOE; report feeds final geochemical/geophysical model | 4/94 |
| S | 8.3.1.3.1.1 | Report available to DOE on modeling of of unsaturated zone water chemistry | 7/94 |
| T | 8.3.1.8.1.1 | Final report on the probability of future volcanic activity available to DOE | 10/94 |
| | | EXPLORATORY SHAFT[b] | |
| A | 8.4.2.3.4 | Start exploratory shaft (ES) site preparation | 12/88 |
| B | 8.4.2.3.4.3 | Start ES-1 shaft construction | 6/89 |
| C | NA | Start ES construction phase testing | 6/89 |
| D | 8.4.2.3.4.4 | Complete connection of ES-1 to ES-2 | 12/90 |
| E | NA | Start in situ phase testing | 12/90 |
| F | 8.4.2.3.4.4 | Complete ES-2 main test level excavation | 9/91 |
| G | NA | Complete exploratory shaft facility Title III activities | 7/92 |

| Major event | Related SCP section | Event description | Date |
|---|---|---|---|
| | | EXPLORATORY SHAFT (continued) | |
| H | NA | Provide available in situ test data for the DEIS | 4/93 |
| I | NA | Provide available in situ test data for the LA | 4/94 |
| | | SURFACE-BASED DRILLING | |
| A | 8.3.1.2.2.3 | Begin drilling deep unsaturated zone holes | 2/89 |
| B | 8.3.1.5.2.1.5 | Complete Ca-Si drilling | 7/89 |
| C | 8.3.1.2.2.3 | Complete drilling of deep unsaturated zone holes | 10/90 |
| D | 8.3.1.4.3.1 | Complete drilling boreholes of the drilling program | 7/92 |

[a]Not applicable.
[b]See Section 8.5.1.2.

### 8.5.6.2 Regulatory and institutional activities and milestones

As shown in Figure 8.5-35, the principal milestones for regulatory and institutional activities include issuance of the SCP and the semiannual progress reports, issuance of the environmental impact statement, and submittal of the license application and other supporting regulatory documents. Because regulatory and institutional milestones were not included in Sections 8.5.1 through 8.5.4, a brief discussion of the preliminary planning basis for regulatory and institutional activities is provided here. The manner in which site information will be utilized in performance and design activities and, finally, in the preparation of regulatory documents is schematically displayed in Figure 8.5-36.

Throughout site characterization, a number of reports, currently called position papers, will be prepared, documenting the DOE's technical and regulatory positions. Position papers will be developed by assimilation of data and information from published reports documenting the results of site program activities and analyses, performance assessment activities, and the design of the waste package and repository. The schedules presented in

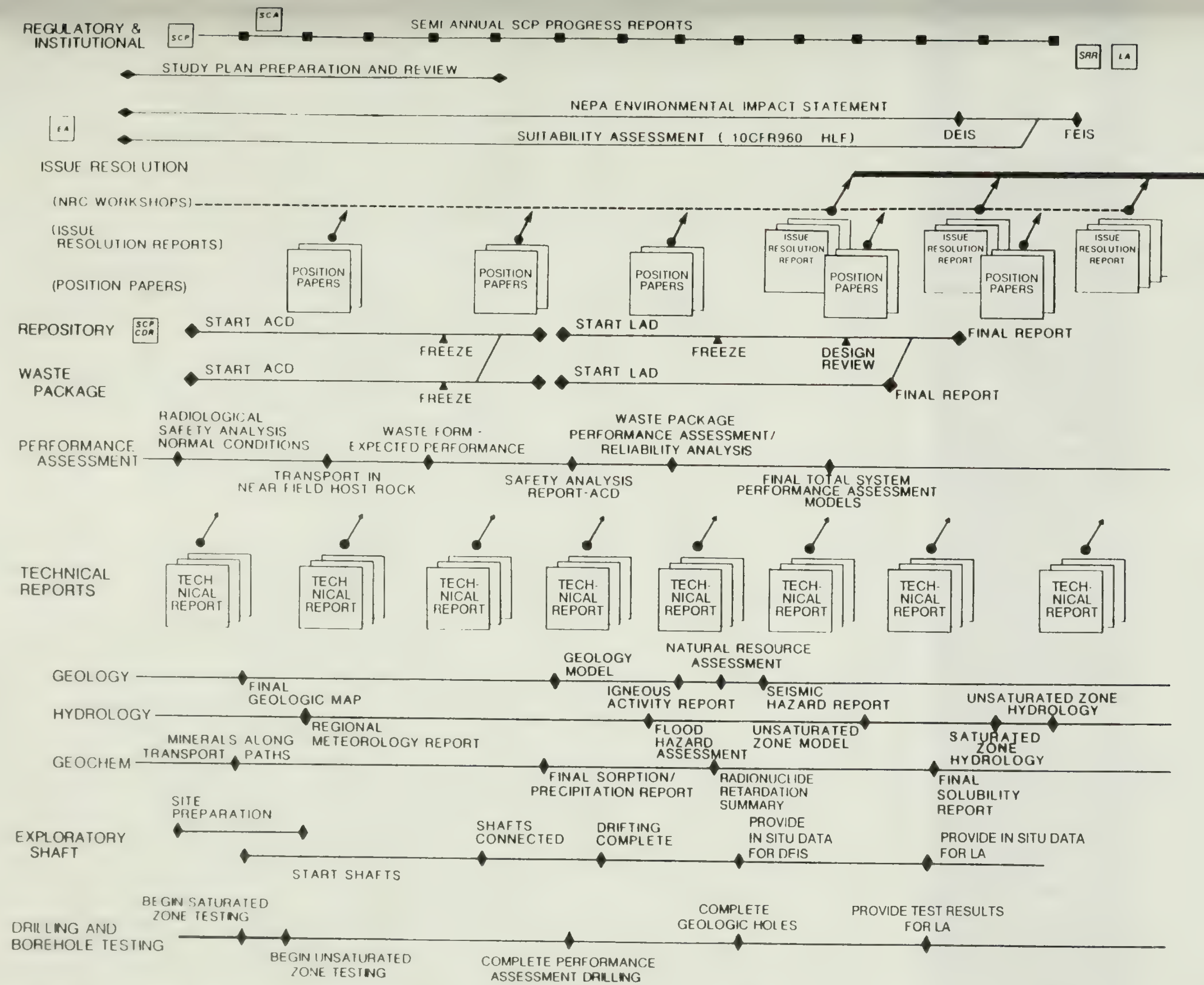


**Figure 8.5-36.** Schematic diagram showing utilization of site data by performance assessment and design, and for preparation of regulatory documents. (ACD advanced conceptual design; DEIS draft environmental impact statement; FEIS - final EIS, HLF - higher-level findings; LA - license application; LAD - LA design; NEPA - National Environmental Policy Act, SCA - site characterization analysis; SCP - site characterization plan; SRR - site recommendation report)

Sections 8.5.1 through 8.5.4, as well as the schedule sections of Section 8.3, include some reports that will serve as input to the position papers. Other documents currently called issue resolution reports, will be prepared to formally document the implementation of the issue resolution strategies defined for performance and design issues in Sections 8.3.2 through 8.3.5. These reports may also be used to document positions on other technical issues of concern to the NRC, State, or public, such as an assessment of the seismic hazards at the Yucca Mountain site or the significance of calcite-silica deposits in faults near the site.

Throughout the issue resolution process, the DOE will be soliciting the views of and interacting with outside organizations, such as the NRC, on selected key topics. Additional information on issue resolution documentation can be found in Section 8.1.2.4. Potential topics to be covered in issue resolution reports are presented in Section 8.2.2.

DOE/RW-0199

*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

*Volume VIII, Part B*

*Chapter 8, Section 8.6, Quality Assurance Program*

*December 1988*

*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

# 8.6 QUALITY ASSURANCE PROGRAM

The Secretary of Energy was assigned the responsibility to carry out the Nuclear Waste Policy Act (NWPA, 1982) and amendments (NWPAA, 1987d). In accordance with the NWPA, these functions have been delegated by the Secretary of Energy to the Office of Civilian Radioactive Waste Management (OCRWM) for the integration of quality assurance (QA) and management policies and requirements for the overview of the activities performed by DOE field operations offices. The Yucca Mountain Project Office of the DOE Nevada Operations Office (DOE/NV) has been delegated the responsibility for the implementation of the technical and QA activities. The OCRWM provides programmatic and policy guidance to the Yucca Mountain Project Office (called the Project Office throughout this section) to ensure that adequate QA and technical objectives of the program are achieved.

This section briefly summarizes the QA program for the Yucca Mountain Project (formerly the Nevada Nuclear Waste Storage Investigations (NNWSI) Project), including reference to the regulatory requirements applicable to the Project and the QA administrative and technical procedures developed by the Project participants to meet the requirements. A detailed description of the Project QA program can be found in the Project quality assurance plan (Project QAP) (DOE, 1988c).

## 8.6.1 QUALITY ASSURANCE PLAN SUMMARY

The DOE policy is that the achievement of quality in fulfilling the responsibilities for the Project is essential to success. To meet this objective, it is necessary to establish effective networks of management plans and procedural controls and to take the necessary actions to demonstrate the ability to safely and efficiently handle and dispose of spent nuclear fuel and high-level radioactive waste. Concurrently, compliance with legislative, regulatory, and DOE requirements for control and documentation of quality must be demonstrated.

The DOE is committed to have a quality assurance program, consistent with 10 CFR 60 Subpart G, in place before the initiation of any new site characterization activities or exploratory shaft construction.

The DOE approach to quality assurance is designed to ensure that activities and engineered items are assigned a level of quality assurance for control and documentation that is consistent with the relative impact on public radiological health and safety, waste isolation, and relative importance to other DOE concerns. The purpose of the QAP is to provide direction to the Project participants to ensure a common approach to meeting the quality requirements that are applied to the Project.

The Project QA program consists of all those planned and systematic actions that are necessary to provide adequate confidence that the mined geologic disposal system (MGDS) will perform satisfactorily. QA includes quality control, which includes those QA activities related to the physical characteristics of a material, structure, component, or system that provide a means by which to control the quality of the material, structure, component,

or system to predetermined requirements. QA provides a multidisciplinary system of quality controls backed by verification activities that demonstrate the completeness and appropriateness of achieved quality.

The assurance of quality is recognized as an interdisciplinary activity involving many organizational components and is not regarded as the sole domain of an organization. It is the responsibility of all Project staff to plan, perform, and document activities affecting quality in accordance with the QAP and develop and implement verification and self-assessment activities to ensure compliance with these requirements. Each Project participant's QA department is responsible for describing, monitoring, and verifying satisfactory accomplishment of quality-related Project activities.

The Project QAP (DOE, 1988c) describes the overall quality assurance requirements for the Project. Quality assurance program plans (QAPPs) of the Project Office and the individual participants of the Project provide documented commitment to the Project QAP. The QAPPs are the documents that describe the participant's QA program and the applicable QA requirements. The quality assurance administrative procedures are those procedures that define and direct controls and control systems making up the Project QA program. These documents are generated by the responsible implementing organization with assistance from the QA organization and in accordance with the requirements of the QAPP. Technical implementing procedures are written by the technical staff to show how they perform individual technical activities in accordance with the QA requirements applicable to their respective disciplines. The details of how each of these organizations will meet quality assurance requirements may differ among the participants. These details are given in the participants' QAPPs listed in Table 8.6-1.

The Project uses an approach to QA that recognizes the differences between engineered items and activities that affect radiological health and safety and waste isolation and those that do not. The approach is designed to ensure that each item or activity is evaluated and assigned a QA level that is consistent with its potential impact or importance, or both, in terms of radiological health and safety, waste isolation, nonradiological health and safety, the U.S. Nuclear Regulatory Commission (NRC) licensing requirements, the operability and maintainability of the repository, costs, and schedules.

The approach to assigning QA levels involves (1) identifying those items and activities whose failure could cause undue risks to the public and facility personnel or extended interruption of facility operation with critical economic losses, or both, and (2) ensuring that these items and activities are covered by QA controls. Alternatively, an item whose failure or malfunction could result only in operational inconvenience or negligible economic loss may deserve only a quality inspection by the purchaser upon the delivery of the item. Between these two extremes, there are varying degrees of QA to achieve the desired confidence in the quality of the completed line of activity.

This approach classifies items and activities into one of three QA levels (QA Level I, II, and III) and further selects the QA requirements and measures to be applied to these items and activities consistent with their importance to safety (QA Levels I and II), waste isolation (QA Level I), and

Table 8.6-1. Organizations participating in the Yucca Mountain Project and their quality assurance programs plans (QAPPs)[a,b]

| Participating Organization | QAPP |
|---|---|
| 1. Yucca Mountain Project Office/ Nevada Operations Office | Waste Management Project Office Quality Assurance Program Plan WMPO-88-1 |
| 2. Lawrence Livermore National Laboratory (LLNL) | Quality Assurance Program Plan --NNWSI Project |
| 3. Los Alamos National Laboratory (Los Alamos) | LANL-NNWSI-QAPP; Quality Assurance Program Plan for Nevada Nuclear Waste Storage Investigations |
| 4. Sandia National Laboratories (SNL) | SNL-NNWSI (Organization 6000) Quality Assurance Program Plan, SLTR 86-0001 |
| 5. United States Geological Survey (USGS) | NNWSI-USGS-QAPP-01, USGS Quality Assurance Program Plan |
| 6. Fenix & Scisson, Inc. (F&S) | F&S Quality Assurance Program Plan QAPP-002 |
| 7. Holmes & Narver (H&N) | H&N-10471-1115, H&N QA Manual |
| 8. Reynolds Electrical & Engineering Company (REECo) | NNWSI QAPP, NTS 568-DOC-115 |

[a]WMPO = Waste Management Project Office, currently called the Yucca Mountain Project Office.
[b]NNWSI = Nevada Nuclear Waste Storage Investigations (Project). The Project has been renamed the Yucca Mountain Project.

the achievement of DOE mission objectives (QA Levels 2 and 3). This will be accomplished by deliberate quality planning and selective application of QA requirements on the item or activity to be performed, with varying degrees of QA applied depending on item or activity function, complexity, consequence of failure, reliability, replicability of results, and economic considerations.

This approach will ensure that all engineered items important to safety or waste isolation (Q-list) and activities important to waste isolation (quality activities list) are identified and controlled in accordance with a QA program that meets the requirements of 10 CFR 60, Subpart G. It will also provide a means to identify other items and activities and an application of

appropriate QA requirements to their control, based on complexity or importance to program goals.

The appropriate QA level for any item or activity is determined by the application of decision criteria and analyses as provided by administrative procedures. The basis for the QA levels and assigned QA requirements is documented. The assigned QA levels and QA requirements must be submitted to the Project Office for review, and approval prior to implementation or use. This review and approval is performed by the Project Quality Manager (PQM) and appropriate Project Office Division Directors. Once a QA level is assigned to an item or activity, the QA level is documented on a QA level assignment (QALA) sheet. The QALA sheet will reference the documented analyses supporting the level assigned to the item or activity. The QALA sheet will also identify the applicable QA criteria, including the identification of and justification of deletion of QA criteria and/or requirements within a criterion. The DOE is currently in the process of revising the existing methodology for assigning QA levels to ensure consistency with, "Technical Position on Items and Activities in the High-Level Waste Geologic Repository Program Subject to Quality Assurance Requirements" (NRC, 1988b), and to require the appropriate documentation and justification for quality level assignments. Following revision of the methodology, all existing quality level assignments will be reevaluated and reassigned, as necessary, and will be supported by appropriate documentation and justification.

The assignment of QA levels will be completed by all participating organizations or the Yucca Mountain Project Office for all engineered items and activities that affect quality associated with site characterization, facility and equipment construction, facility operations, performance confirmation, permanent closure, and decontamination and dismantling of surface facilities. The assigned QA levels and QA requirements will be documented and submitted to the Yucca Mountain Project Office for review, and approval prior to implementation or use. This review and approval will be performed by the Project Quality Manager and appropriate Project Office Division Directors. Once assigned, the QA level for a particular item or activity shall be applied by all Project participants involved in the activity.

Data or data interpretations generated as a result of activities not controlled in accordance with a 10 CFR 60, Subpart G QA Program, or activities performed before the complete implementation (acceptance by the NRC) of the Project QAP will not be used in the licensing process as primary information for items and activities important to safety and/or waste isolation unless qualified in accordance with administrative procedures meeting the guidance provided in "Qualification of Existing Data for High Level Nuclear Waste Repositories" (NRC, 1988a), or other method accepted by the NRC.

The following is a discussion of QA Levels I, II, and III and a description of their applications.

QA Level I is assigned to those radiological health and safety related items and activities that are important to either safety or waste isolation and that are associated with the ability of a geologic nuclear waste

repository to function in a manner that prevents or mitigates the consequences of a process or event that could cause undue risk to the radiological health and safety of the public. Items important to safety are those engineered structures, systems, components, and related activities essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body or to any organ of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until the completion of the permanent closure of the repository. Items and activities important to waste isolation are those natural and engineered barriers and related activities that are relied on for achieving the postclosure performance objectives in 10 CFR 60 Subpart E, which refers to the environmental standards established in 40 CFR 191. Items important to safety and engineered barriers important to waste isolation will be placed on a Q-list in accordance with the NRC technical position on QA requirements document (NRC, 1988b). Similarly, major activities conducted during site characterization, construction, operation, or closure that may adversely impact the natural barriers important to waste isolation will be placed on a quality activities list in accordance with NRC (1988b). The Q-list and quality activities list are discussed further in Section 8.6.4.2.

QA Level I is to be applied to those items and activities that may affect the ability of the repository to meet the preclosure and postclosure performance objectives specified by the NRC and the U.S. Environmental Protection Agency (EPA) for protecting public health and safety from radiological hazards. QA Level I control and documentation must be applied to activities, including site characterization, scientific investigations, facility and equipment design, procurement, construction, facility operation, performance confirmation, permanent closure, and decontamination and decommissioning of surface facilities when they are specifically concerned with the protection of the public's health and safety with respect to a radiological hazard. A high-level radioactive waste repository will use engineered systems, structures, and components to contain the waste and ensure preclosure safety. The repository also will use the natural barriers to afford postclosure isolation. Within this context, QA Level I will be applied to

1. Items that could affect the preclosure radiological health and safety of the general public. Specifically, this means items and activities that could cause, or result in, an accident that could result in a radiation dose, either to the whole body or to any organ, of 0.5 rem or greater, either at or beyond the nearest boundary of the unrestricted area, at any time until the permanent closure of the repository.

2. Activities that will provide primary data (as defined in the Project QAP (DOE, 1988c)) that will be relied on for design and performance assessment of the repository system. These data are the field and laboratory data and subsequent analyses that provide the basis for determining and demonstrating that the natural and the engineered systems of the repository are capable of meeting the performance objectives for waste containment and isolation. This includes all experiments and research that have a significant impact on site characterization or are an essential part of the data base that

directly support the final design of the repository and waste package performance.

3. Activities that could adversely impact the waste isolation capabilities of the engineered and natural barriers.

4. Items that are relied on to meet the postclosure performance objectives of the engineered barriers of the repository system.

5. Items and activities that, having failed, could cause a failure of a QA Level I item, or irretrievable loss of QA Level I data.

6. The design phase that involves the preparation of detailed design documents for engineered items important to safety or waste isolation (such as drawings, specifications, and analyses) will be assigned a QA Level of I. One of the purposes of this design phase is to define items that will be procured or constructed as a result of the design activity. The definition of items includes a detailed description of their function and interrelationships. As the design phase proceeds, and the QA level for items is identified and approved, design, procurement, and construction activities shall be governed by the QA level assigned to the item.

QA Level II is assigned to those activities and items related to the systems, structures, and components that require a level of QA sufficient to provide for reliability, maintainability, public and repository worker nonradiological health and safety, repository worker radiological health and safety and other operational factors that would have an impact on DOE and Yucca Mountain Project Office concerns, and on the environment.

QA Level II controls and documentation shall be applied to the Project items and activities (described below) that are associated with nonradiological operation of the exploratory shaft facilities and repository and the radiological safety of the repository worker. The high-level waste (HLW) repository will use engineered systems, structures, and components that must be designed, constructed, fabricated, tested, and operated to meet the operational performance objectives and to minimize nonradiological hazards to the public and repository worker, and radiological hazards to the repository worker. Additionally, activities that have a major impact on Project costs or schedules that could delay the achievement of DOE/Office of Civilian Radioactive Waste Management (OCRWM) milestones must be appropriately controlled. Therefore, QA Level II must be applied as follows:

1. Engineered items that are essential to the design, construction, and operation of the repository or of the exploratory shaft facility, and could have a major impact on the nonradiological health and safety of the public and repository workers.

2. Items that could affect the retrievability of waste up to the time of repository closure.

3. Items, if having failed or if performed inadequately, would cause repository workers to be exposed to radiation or radioactive

contamination levels in excess of the limits expressed in 10 CFR Part 20.

4. Items and activities involving the nonradiological operational reliability and maintainability of engineered systems, structures, or components.

5. The design phases that involve the comparative technical analysis of alternatives, methods, or equipment are conducted to determine which alternative, method or equipment is preferred shall be assigned a QA level of II prior to execution. Where a particular item can be identified during this phase, a separate QA-level assignment may be made for that item. Once the QA-level assignment for that item is approved, design activities associated with the item shall be governed by the QA level assigned to the item.

6. Items whose failure could result in a major cost overrun.

7. Items whose failure could result in a major schedule slippage.

QA Level III is assigned to those items and activities not classified as QA Levels I or II.

## 8.6.2 REQUIREMENTS FOR QUALITY ASSURANCE

The quality assurance requirements for the Yucca Mountain Project originate from three main sources as depicted in Figure 8.6-1 and listed below:

1. U.S. Nuclear Regulatory Commission

   a. 10 CFR Part 60 Subpart G, Disposal of High Level Radioactive Wastes in Geologic Repositories - Quality Assurance

   b. 10 CFR Part 50 Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants

   c. NRC Review Plan: Quality Assurance Programs for Site Characterization of High-Level Nuclear Waste Repositories (June, 1984) (NRC, 1984d)

2. U.S. Department of Energy orders

   a. DOE 5700.6A (9/23/86), Quality Assurance

   b. NV 5700.6-6 (3/13/87), Quality Assurance

3. Office of Civilian Radioactive Waste Management (OCRWM)

   a. OCRWM Quality Assurance Management Policies and Requirements, DOE/RW-0032 (October, 1985) (DOE, 1985d)

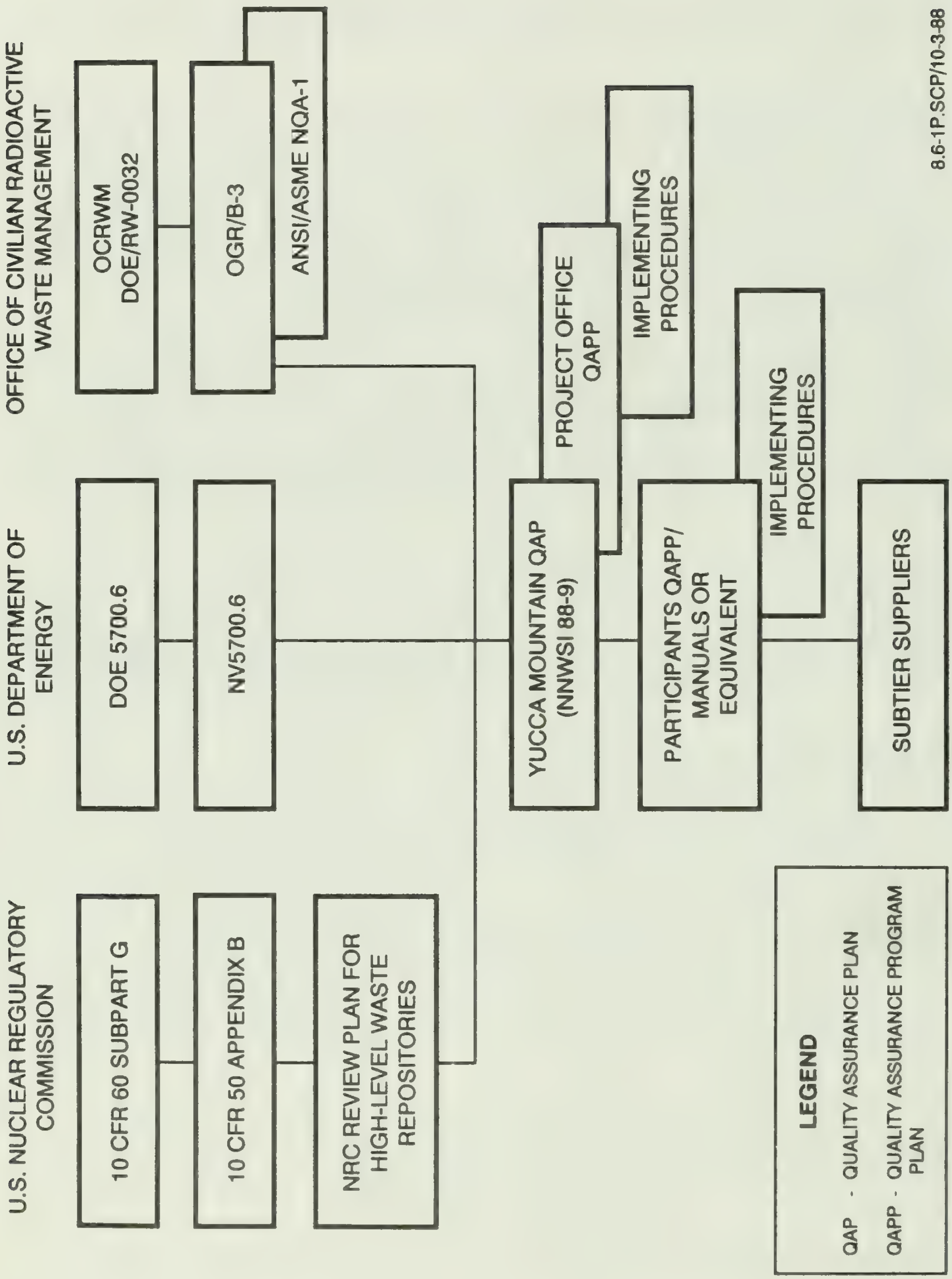


**Figure 8.6-1.** Sources of criteria for quality assurance.

b. OGR/B-3, OGR Quality Assurance Plan for High Level Radioactive Waste Repositories (August, 1986) (DOE, 1986g)

c. ANSI/ASME NQA-1, American National Standard for Quality Assurance Program Requirements for Nuclear Facilities (ANSI/ASME NQA-1-1986) (ANSI/ASME, 1986)

The NRC, by way of 10 CFR 60 Subpart G, has made the quality provisions of 10 CFR 50, Appendix B, mandatory for all systems, structures, and components designated as "important to safety" or "important to waste isolation" and activities related thereto. The NRC has also published the NRC review plan (NRC, 1984d). This document has two purposes: (1) to define the criteria and methods for NRC review of the QA program for site characterization during the prelicensing phase and (2) to provide guidance for establishing an acceptable program for items designated as "important to safety" or "important to waste isolation" and activities related thereto. In addition, the NRC has issued various technical positions to provide detailed guidance on the implementation of an aspect of a QA program.

DOE Orders DOE 5700.6A and NV 5700.6 provide policy, set principles, and designate responsibility for the implementation of DOE plans and actions to ensure quality achievement and verification for the DOE and the Nevada Operations Office, respectively. The OCRWM quality assurance management policies and requirements document (DOE, 1985g) sets forth overall, integrated QA management policies and requirements for the entire OCRWM Program and provides a general framework for the development of more detailed QA management policies and requirements by program, project, and contractor organizations.

The <u>OCRWM Quality Assurance Plan for High-Level Waste Repositories</u> (OGR/B-3) (DOE, 1986g) provides that the basic and supplementary requirements included in the American National Standards Institute/American Society of Mechanical Engineers (ANSI/ASME) <u>Quality Assurance Program Requirements for Nuclear Facilities</u>, NQA-1-1986 (ANSI/ASME, 1986) is the standard for the implementation of quality assurance programs for DOE projects. The ANSI/ASME requirements also provide an adequate basis for interpreting the pertinent quality assurance requirements of 10 CFR Part 50, Appendix B (NRC, 1987b), for the establishment and execution of QA programs during the design and construction phases of nuclear facilities.

The DOE-OCRWM is currently in the process of developing, and obtaining NRC approval of, upper-level QA program documents. These documents include a QA requirements document (QAR) and a QA program description (QAPD). Upon acceptance by the NRC, the OCRWM QAR and QAPD will replace OGR/B-3 (DOE, 1986g) as the governing QA program documents for the Project QA program.

To ensure uniform and acceptable interpretation of the requirements for quality assurance, the Project QAP (DOE, 1988c), was prepared for Project activities. The purpose of this document is to provide interpretations of the quality assurance requirements appropriate to site characterization, and the design of engineered items for an NRC-licensed geologic repository. The Project QAP consolidates all requirements of the above DOE and NRC documents into a single, site-specific document that provides clear interpretations of

the federally mandated quality assurance requirements as they apply to Project scope of work.

The Project QAP is outlined in a similar format to the ANSI/ASME quality assurance program requirement document (ANSI/ASME, 1986). The difference in the format is the identification of the QA criteria that are applicable to either the control of engineered items or the control of scientific investigations. The QA requirements contained in the Project QAP are applied to items and activities classified as QA Level I and II. Deviations from requirements within applicable criteria are permissible for QA Level II items and activities provided that adequate justification is documented. The requirement imposed for QA Level III items and activities are those managerial, administrative, scientific, engineering, commercial, and laboratory practices that are commonly used by the organizations participating in the Project.

## 8.6.3 ORGANIZATION OF THE PROJECT WITH RESPECT TO QUALITY ASSURANCE

This section describes organizational responsibilities and interfaces within the Yucca Mountain Project with respect to QA. The organization of the Project is shown in Figure 8.6-2. The Project Work Breakdown Structure (WBS) dictionary provides the technical and management responsibilities of each participating organization and Nevada Test Site (NTS) support contractor. Definitive descriptions of the QA responsibilities are contained in the quality assurance program plans (QAPPs) of each Project participant. The specific requirements that must be addressed in the QAPPs are contained in Sections 8.6.1 and 8.6.2 of this document.

The Secretary, U.S. Department of Energy Headquarters (DOE/HQ), was given the responsibility to carry out the Nuclear Waste Policy Act (NWPA, 1982) and amendments (NWPAA, 1987). This responsibility has been delegated by the DOE Secretary to the OCRWM for the integration of QA and management policies and requirements for the overview of the activities performed by DOE field operations offices. The DOE Nevada Operations Office (DOE/NV) operations office has been delegated the responsibility for the implementation of the technical and QA activities of the Project.

The OCRWM provides programmatic and policy guidance to the Yucca Mountain Project Office (Project Office) to ensure that adequate QA and technical objectives of the program are achieved. Specifically, the OCRWM is composed of the following offices: Program Administration and Resources Management, Facilities Siting and Development, Systems Integration and Regulation, External Relations and Policy, and the Office of Quality Assurance. These OCRWM offices provide direction to the Project Office for the implementation of the OCRWM program objectives. Technical adequacy of the work performed shall be determined via audits, technical reviews, etc., as appropriate.

The OCRWM Office of Quality Assurance provides QA guidance and overview to the Project by (1) review and approval of the Project quality assurance plan, and the Project Office QAPP; (2) specifying applicable requirements which are contained in the OCRWM quality assurance plan; (3) performance of

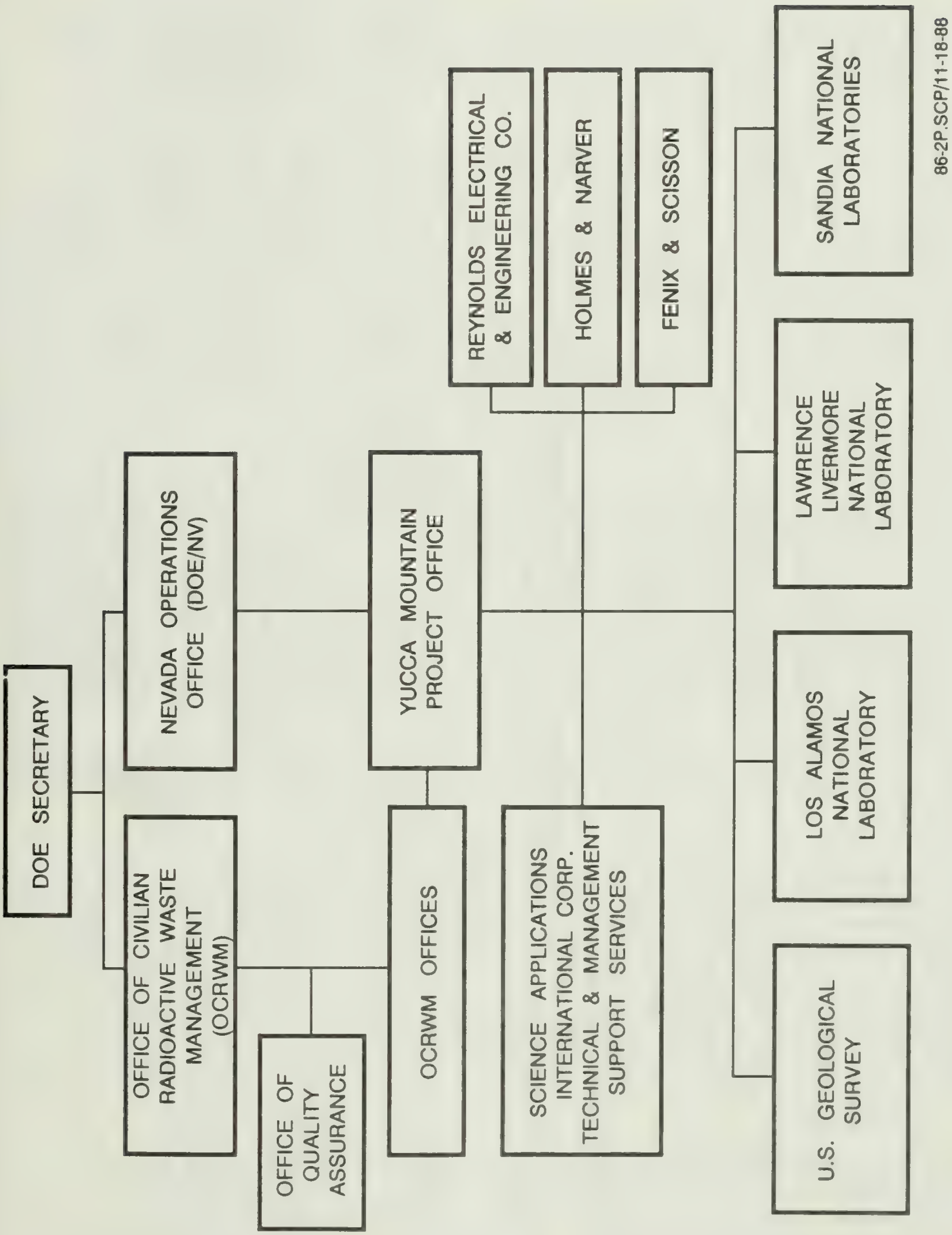


**Figure 8.6-2.** Yucca Mountain Project organization.

QA audits and surveillances of the Project Office; and (4) participating as observers of selected audits of Project Office contractors.

The DOE/NV Manager has the ultimate responsibility and accountability for the Project within the Nevada Operations Office. The Project Office has been established within the DOE/NV organization for the management of the Project. The Project Office operates as a part of the DOE/NV under the programmatic direction of the OCRWM.

The Project Office has responsibility for authorization of work and management and technical direction of the activities of the participating organizations and Nevada Test Site support contractors through the issuance of technical and programmatic guidance, technical integration of the Project, Project planning and documentation, and QA programmatic guidance. Technical adequacy of the work performed shall be determined via audits, design reviews, technical reviews, management assessments, etc., as appropriate. In addition, the Project Office is responsible for conducting the technical activities described under the responsibilities of the appropriate Project Office Division Director. An organizational chart depicting the Project Office organization is provided in Figure 8.6-3.

The Project Manager, Project Office, is responsible for the Project management that encompasses (1) planning and directing activities; (2) establishing goals and objectives, and assessing progress toward the attainment of those goals; (3) administration of procurement of materials and services; (4) preparation and issuance of technical and programmatic guidance; (5) organization and conduct of peer reviews; (6) compliance with laws, regulations, and DOE policies; and (7) other administrative duties. In addition, the Project Manager, Project Office, is responsible to ensure implementation of the Project Office QA Program for the conduct of Project Office quality-related activities and the implementation of corrective actions.

The technical and quality achievement responsibilities of the Project Office focus in three areas, each under the direction of a Division Director.

The Regulatory and Site Evaluation Division of the Project Office is responsible for (1) site characterization in field and laboratory activities; (2) performance assessment; (3) NRC interactions; (4) preparation of project documents required by the Nuclear Waste Policy Act and the NRC (including preparation of the site characterization plan, progress reports, study plans, technical input to the environmental impact statement (EIS) and license application, position papers, and other reports for use in the license application to NRC); (5) preparation and review of site investigation documents; and (6) review and approval of Yucca Mountain Project quality-related documents.

The Technology Development and Engineering Division of the Project Office is responsible for (1) systems description, analysis, and integration; (2) waste package design and development; (3) design, construction and operation of major test facilities; (4) operational safety; (5) repository engineering; (6) instrument and equipment development; (7) exploratory shaft

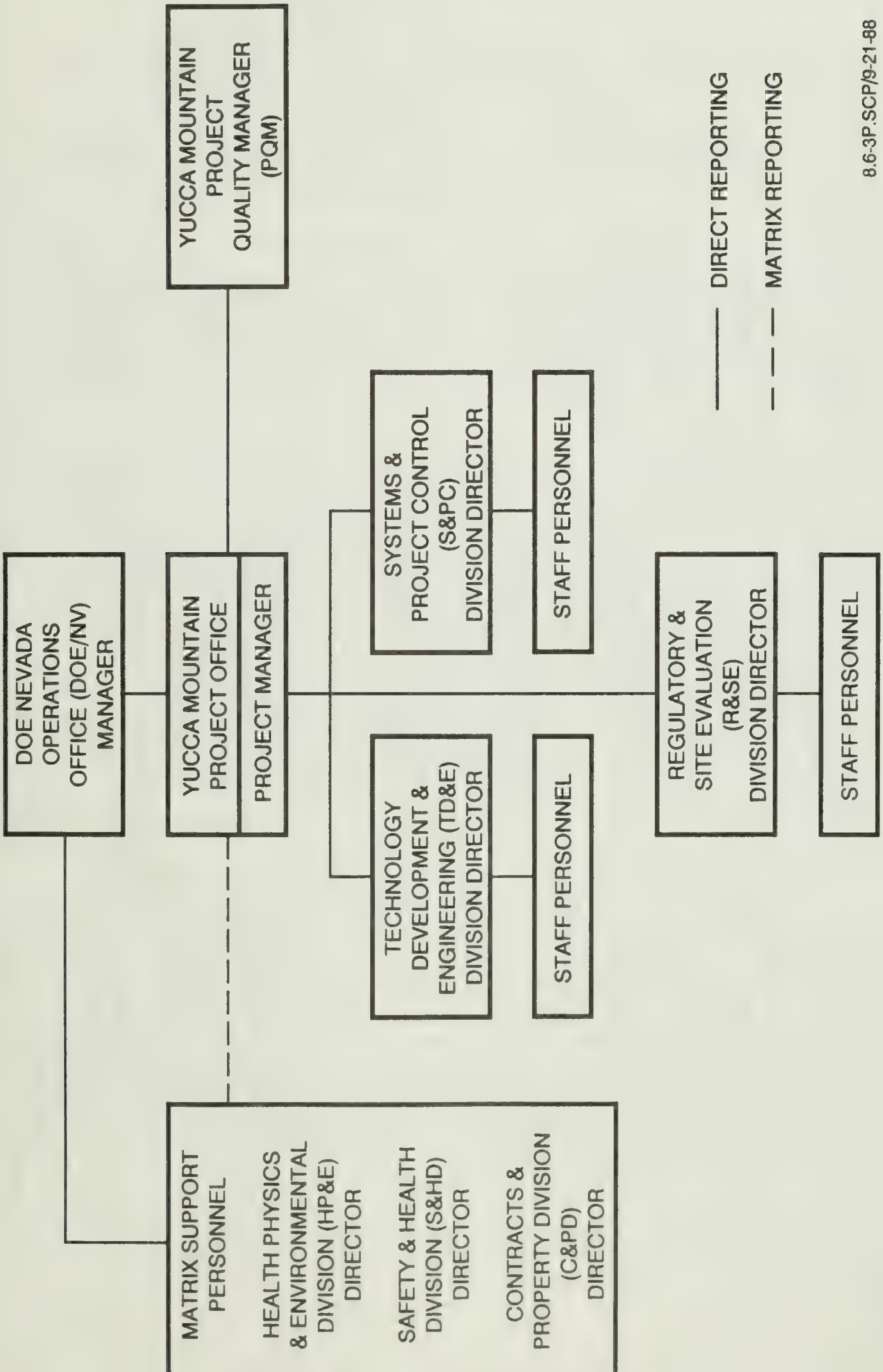


**Figure 8.6-3.** Organization of the Yucca Mountain Project Office.

design, construction, and operation; (8) engineering and technical support; and (9) review and approval of Yucca Mountain quality-related documents.

The Systems and Project Control Division of the Project Office is responsible for (1) administration and management support to integrate and control the Yucca Mountain Project, (2) records management/information management system, (3) quality assurance records administration, (4) configuration management, (5) transportation, (6) socioeconomics, (7) institutional liaison, (8) Project training, (9) review and approval of Project quality-related documents, and (10) environmental analysis and support.

All Project Office Division Directors are responsible for implementing the QA program in their area of responsibility. The QA responsibilities for development, interpretation and overview of the Project QA program is accomplished through the efforts of the Project Quality Manager (PQM) and his organization. The overall responsibility to ensure that QA control and documentation is maintained throughout the Project is retained by the Project Office.

The Project Office utilizes a matrix management organizational concept to support Project activities. The administrative responsibility for DOE/NV personnel supporting the Project remains with the respective DOE/NV organizational element, while the functional responsibility of DOE/NV personnel performing Project activities is to the Project Office. Personnel from participating organizations and NTS support contractors may also be matrixed to the Project Office. The organization of the Project Office with respect to QA is shown in Figure 8.6-4 as one organization with the major DOE/NV divisions that provide matrix support staff. The DOE/NV staff assists the Project Manager, Project Office, by providing reviews, recommendations, and expertise on various aspects of the Project in terms of their respective responsibilities as established in accordance with the matrix management approach. Matrix support personnel work under the implementing procedures of the Project Office QAPP.

The Project Office PQM is responsible for development, interpretation and overview of the overall Project QA program and has appropriate organizational position, responsibilities, and authority to exercise proper control over the Project Office QA program. This position is occupied by an individual with appropriate QA knowledge and experience. The PQM reports functionally to the Project Manager, Project Office, for the maintenance and implementation of the Project QAP and the Project Office QAPP. The PQM is at the same or higher organizational level as the highest line manager responsible for activities affecting quality and is sufficiently independent from cost and schedule considerations. The PQM has effective communication channels with other senior management positions. An organization chart depicting the Project Office QA organization is shown in Figure 8.6-4.

Responsibilities of the PQM to the Project includes (1) approval of the Project QAP (DOE, 1988c); (2) approval of quality-related Project administrative procedures (AP-Q); (3) approval of Project participant QAPPs and changes thereto, (4) approval of the Project Office QAPP, its implementing procedures, and all changes thereto; (5) the responsibility and authority to verify the adequacy and effectiveness of QA plans, requirements, and QA program implementation by the Project Office and Project participants

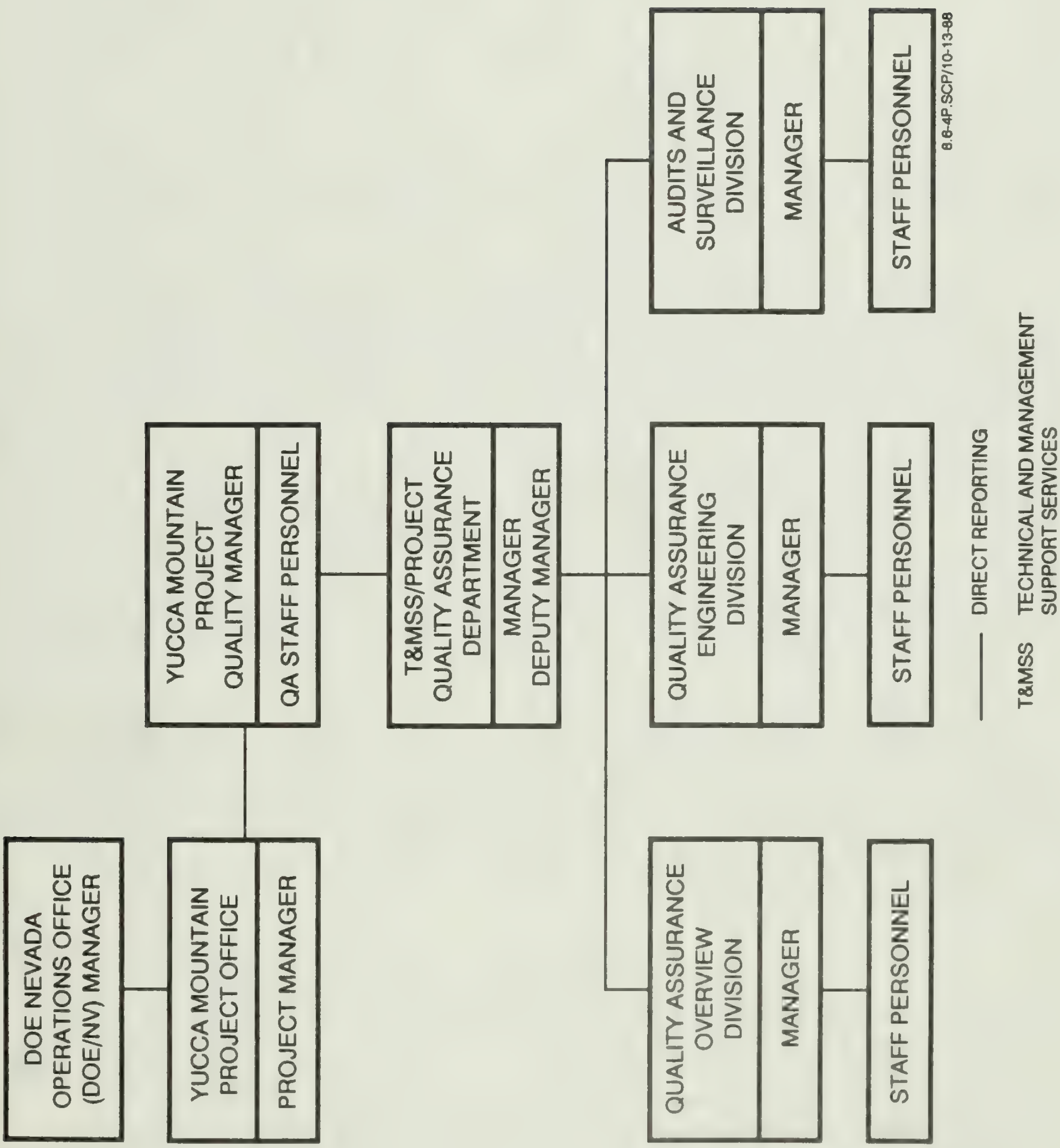


**Figure 8.6-4.** Yucca Mountain Project Office quality assurance organization.

through the direction of audits and surveillances; and (6) coordination of Project Office QA activities. The PQM is supported by the Science Applications International Corporation/Technical and Management Support Services (SAIC/T&MSS) Project QA Department to conduct these activities.

The Project QA organizational structure is such that if disputes in QA arise between the PQM and others (e.g., Division Directors, Project participants, etc.), the disputes will be directed to the Project Manager, Project Office for arbitration. If not satisfied with the decision, the PQM has the authority to have the DOE/NV Manager arbitrate. If still not satisfied with the resolution of the problem, the PQM has the responsibility to notify the Office of Quality Assurance, OCRWM.

Upon the request of the Project Office the Health Physics and Environmental Division (HPE) may provide matrix support personnel to the Project Office and are responsible for review of procedures, facility designs, and operations plans applicable to radiological monitoring of the environment, radiological health of the public and radiological workers, compliance with environmental laws, and radiological operations of the DOE/NV, its contractors, or the national laboratories at the Nevada Test Site. The HPE acts on requests for support submitted by participating organizations through the Project Office and provides design reviews, advice, and assistance to the Project Office.

Upon the request of the Project Office, the Safety and Health Division (S&HD) may provide matrix support personnel to the Project Office and are responsible for review of procedures, facility designs, and operations plans applicable to the occupational health and industrial and fire safety of site workers and facilities. The S&HD acts on requests for support submitted by participating organizations through the Project Office and provides document reviews, advice, and assistance to the Project Office.

Upon the request of the Project Office, the Contracts and Property Division (CPD) may provide matrix support personnel to the Project Office and are responsible for preparing and negotiating contracts and other agreements with the national laboratories and other federal agencies (except the NRC for which DOE/HQ is responsible) on behalf of the DOE/NV in support of the Project. The CPD acts on requests for support submitted by the Project Office and provides procurement package reviews, advice, and assistance to the Project Office.

SAIC/T&MSS provides broad technical, operational, and managerial support for Project activities and performs these functions in accordance with the requirements of the Project Office QAPP (DOE/NV, 1988). SAIC/T&MSS efforts involve both the direct provision of technical, scientific, and institutional expertise and the management and integration of support provided by all Project participants in connection with planning, design, field investigations, laboratory work, construction, and regulatory licensing and institutional activities related to the Project. SAIC/T&MSS assists the Project Office in such areas as (1) the identification and analysis of, and compliance with, applicable statutory, regulatory, and program requirements; (2) the development and execution of project management plans and strategies;

(3) the monitoring and coordination of work performed by project participants, including the review of their work for completeness, technical sufficiency, and compliance with project requirements; (4) the preparation of assigned management, technical, and scientific reports and studies; (5) the presentation to the public, the program office, and affected Federal, State, and other agencies of project positions, plans, and other project related information; (6) the execution, on an assigned basis, of any of the activities specified by the OCRWM-approved work breakdown structure; and (7) quality assurance.

The SAIC/T&MSS organization is composed of six major operating departments and a Project Institutional Relations Office reporting to the T&MSS Project Manager. In addition, the T&MSS/Project QA Department reports administratively to the SAIC Sector Manager and functionally to the Project Office Project Quality Manager to assure independence. The following section describes the responsibilities T&MSS/Project QA department.

The responsibilities of the SAIC/T&MSS Project QA Department are to provide support to the PQM in the development, maintenance, documentation, administration, and implementation of the Project QAP, and the Project Office QAPP. SAIC/T&MSS Project QA Department activities include conducting and participating in QA audits; overview; QA surveillance and monitoring of the Project Office integrated technical activities; policy guidance; review of the QAPPs prepared by the participating organizations and NTS support contractors for compliance to the Project QAP (DOE, 1988c); and review of the Project quality-related documents as defined in the Project Office implementing procedures for compliance to Project QA requirements.

The major organizations participating in the Project, the designated functions of these organizations and their relationship with the Project Office are explained below. Nevada Test Site support contractors and Participating organizations are responsible to the Project Office for technical activities assigned to them as specified in the Project Work Breakdown Structure (WBS) dictionary and Project-specific technical plans. The technical activities are to be accomplished in accordance with the QA requirements in the Project QAP (DOE, 1988c), and their respective QAPPs when approved by the Project Office.

#### 8.6.3.1 Nevada Test Site support contractors

Support contractors at the Nevada Test Site include the following organizations:

1. Fenix & Scisson, Inc. (F&S) is the exploratory shaft facility (ESF) architect-engineer for drilling and mining for the Project. F&S responsibilities also include field surveillance and inspection of drilling and mining, and subsurface facilities construction and testing.

2. Holmes & Narver, Inc. (H&N) is the ESF architect-engineer responsible for the design of the underground support systems and the surface facilities. Responsibilities include field surveillance and

inspection of facilities construction. Additionally, they provide material test laboratory support, nondestructive examination services, and field surveying services, microfilming, and archival storage of Project records.

3. Reynolds Electric and Engineering Company (REECo) is the prime support contractor providing support for subsurface and surface construction, drilling, and mining. REECo assists in the operation and maintenance of the site facilities and provides procurement and logistical activities for the Project when requested.

### 8.6.3.2 Yucca Mountain Project participants

The Yucca Mountain Project participants are as follows:

1. Lawrence Livermore National Laboratory (LLNL) is responsible for the development of the waste package for emplacement in tuff, which includes the definition of the package environment, material development and testing, package design, performance analysis, and testing; and provides assistance to other Project participants in areas of specialized expertise.

2. Los Alamos National Laboratory (LANL) is responsible for nuclide migration, geochemistry, mineralogy, and petrology studies. Los Alamos acts as the lead technical organization for the coordination and scheduling of the exploratory shaft testing program. Los Alamos also provides assistance to other Project participants in areas of specialized expertise.

3. Sandia National Laboratories (SNL) is responsible for (a) repository systems development; (b) data management and analysis; (c) systems performance assessment of the repository; (d) conceptual design of the repository; (e) determination of the thermal and mechanical property of the host rock; (f) repository sealing performance requirements, materials, evaluation, design, and testing. SNL also provides assistance to other Project participants in areas of specialized expertise.

4. The United States Geological Survey (USGS) is responsible for (a) site characterization of geology, hydrology, tectonics, igneous activity, regional climate, and seismicity and (b)acts as lead technical participant for the site characterization drilling activities. The USGS also provides assistance to other Project participants in areas of specialized expertise.

QA personnel throughout the Project report to management levels such that they have sufficient authority and organizational independence to identify quality problems; to initiate, recommend, or provide solutions; to verify implementation of solutions; and to stop unsatisfactory work.

The organizational structure for executing the QA programs varies from organization to organization, and each is described in the individual

organization's QAPP. The Technical Project Officer of the respective participating organizations and Nevada Test Site support contractors are responsible to the Project Manager, Yucca Mountain Project Office, to ensure that the Project activities for which they are responsible are performed in accordance with a QAPP and implementing procedures that meet the requirements of the Project QAP (DOE, 1988c).

## 8.6.4 APPLICATION OF QUALITY ASSURANCE

### 8.6.4.1 Quality assurance before site characterization

Requirements for a formal, documented QA program for the Yucca Mountain Project Office and the Project participant contractors were established at the beginning of site exploration activities (December 1, 1977). These requirements were initially in orders issued by DOE and redefined in the DOE-HQ Order 5700.6A and in the Project QAP (DOE, 1988c), which was approved in August, 1980. These QA documents established the requirement that activities affecting quality be defined and documented in appropriate directives, policies, procedures, and instructions, and applied to data gathering and other activities during site exploration. In response, the contractors responsible for conducting the site exploration activities established QA plans and QA administrative and technical implementing procedures.

The QA program for site exploration evolved from 1977 to 1986 and incorporated requirements in effect at the time work was performed. The program was modified as new requirements were imposed or requirements were adopted by the Project to improve program validity. During site exploration, data were gathered, which may be used for characterization and to support possible license application. If any of these data are identified as primary information in support of items and activities important to safety or waste isolation they will be qualified against the current QA program on a case-by-case basis in accordance with approved administrative procedures incorporating the guidance provided in Qualification of Existing Data for High-Level Nuclear Repositories (NRC 1988a), or other methods accepted by the NRC.

### 8.6.4.2 Quality assurance during site characterization

This section describes the methods for determining which items and activities are to be controlled by the QA program during site characterization.

Before starting any new site characterization activities or exploratory shaft construction, each Project participant will evaluate their assigned tasks to identify and classify engineered items and activities that require application of a 10 CFR 60 Subpart G QA program. This evaluation will be consistent with NRC technical positions on QA requirements document (NRC, 1988b). This document provides guidance on how to identify items (including structures, systems, and components) and activities subject to quality assurance requirements of 10 CFR 60 Subpart G for both the preclosure and

postclosure phases of the repository. In the preclosure phase, items that are essential to the prevention or mitigation of an accident that could result in an offsite radiation dose of 0.5 rem or greater are termed "important to safety." In the postclosure phase, the natural and engineered barriers that are relied on to meet the postclosure performance objectives are considered "important to waste isolation."

The NRC technical position on QA requirements document describes the development of the Q-list and the quality activities list (NRC, 1988b). The list of items that are considered important to safety and engineered barriers that are important to waste isolation is termed the "Q-list." The quality activities list includes those activities conducted during site characterization, construction, operation, and closure that relate to natural barriers considered important to waste isolation. Such activities include data gathering, performance assessment, and activities that could affect a natural barriers ability to isolate waste. Items and activities identified on the Q-list and the quality activities list shall be governed by a QA program that meets the requirements of 10 CFR 60 Subpart G.

As the design matures and as additional information is obtained about the characterization of the site, some items and activities may be added to as well as deleted from, the Q-list or quality activities list. The new input will be factored into the analysis to determine those items or activities important to safety or waste isolation and will be consistent with NRC (1988b). As described in NRC (1988b), the semiannual progress reports to the SCP will highlight the additions or deletions to the lists and will reference the documented analyses.

### 8.6.4.2.1 Preliminary Q-list items

Sections 6.1.4 and 6.1.5 describe the general methodology used to identify the items important to safety and engineered barriers important to waste isolation, which make up the Q-list. As discussed in Section 6.1.4, and documented in Appendices F and L of the SCP-Conceptual Design Report (SCP-CDR) (SNL, 1987), the Q-list methodology has been applied to structures, systems, and components of the repository, including shafts. While the structures, systems, and components of the exploratory shaft facility were not explicitly discussed in the SCP-CDR, intake and exhaust shaft components were determined not to be important to safety. Additionally, no shaft components were identified as engineered barriers important to waste isolation using the performance allocation process. Currently, however, DOE is reviewing the documentation used to develop the Q-list, specifically addressing the structures, systems, and components important to safety, and engineered barriers important to waste isolation that could be part of the exploratory shaft facility. This review and documentation will be consistent with the guidance provided in NRC (1988b).

8.6.4.2.2 Preliminary quality activities list

The quality activities list is a list of activities associated with the assessment of the natural barriers important to waste isolation and the activities whose undertaking could adversely affect the performance of natural barriers.

Identification of activities that are on the quality activities list is determined by the definition and understanding of a quality activities list provided by NRC (1988b). That is, an activity conducted during site characterization, construction, operation, or closure will be on the quality activities list if (1) the activity will provide data to be relied on in performance assessments of the waste isolation capabilities of the natural barriers, (2) the activity is related to actual performance assessments, or (3) the activity may adversely impact the waste isolation capabilities of the natural barriers.

A preliminary quality activities list is presented in this section. This list was developed by (1) identifying the major types of activities described in Section 8.3 and (2) identifying those activities that meet one of the three criteria described above. Activities that were determined to meet one of the criteria above are considered to be on the preliminary quality activities list.

The preliminary quality activities list presented below is general in nature and will evolve into the quality activities list as program participants evaluate their assigned tasks to identify and classify individual activities that require application of a 10 CFR Part 60 Subpart G QA program. The DOE is currently in the process of developing a procedure for identification of items and activities that require control under a 10 CFR Part 60 QA program. This procedure will require evaluation of the impact of activities on the waste isolation capability of the site. If it cannot be reasonably demonstrated that an activity should not be on the quality activities list, the activity will be controlled under a 10 CFR Part 60 Subpart G QA program until adequate justification is provided.

The preliminary quality activities list includes the following major activities.

<u>Activities related to site characterization</u>

These activities provide data that will be used to characterize the natural barriers and potentially will be used as primary data for postclosure performance assessments. Included are all data collection, data analyses, and modeling activities described in Section 8.3 for the following site characterization programs:

| Section | Site Program |
|---|---|
| 8.3.1.2 | Geohydrology |
| 8.3.1.3 | Geochemistry |
| 8.3.1.4 | Rock characteristics |
| 8.3.1.5 | Climate |

| Section | Site Program |
|---|---|
| 8.3.1.6 | Erosion |
| 8.3.1.7 | Rock dissolution |
| 8.3.1.8 | Postclosure tectonics |
| 8.3.1.9 | Human |
| 8.3.1.12* | Meteorology |
| 8.3.1.15* | Thermal and mechanical rock properties |
| 8.3.1.16* | Preclosure hydrology |
| 8.3.1.17* | Preclosure tectonics |
| 8.3.4.2 | Waste package characteristics (postclosure) |

The programs marked with an asterisk in the previous list contain activities that provide input to both preclosure and postclosure assessments. The activities supporting postclosure assessments are included on the quality activities list.

Activities related to postclosure performance assessment

These activities relate to the postclosure performance assessment that includes the natural barriers. Included are the performance assessment activities described under the following subsections of Section 8.3:

| Section | Issue |
|---|---|
| 8.3.5.9 | Containment by waste package (Issue 1.4) |
| 8.3.5.10 | Engineered barrier system release rates (Issue 1.5) |
| 8.3.5.12 | Pre-waste-emplacement ground-water travel time (Issue 1.6) |
| 8.3.5.13 | Total system performance (Issue 1.1) |
| 8.3.5.14 | Individual protection (Issue 1.2) |
| 8.3.5.15 | Ground-water protection (Issue 1.3) |

Activities that may affect a natural barriers ability to isolate waste

Natural barriers that are relied on to meet the performance objectives relating to waste isolation have been identified as part of the performance allocation process (Section 6.1.5). Major construction, operation, and site characterization activities that may adversely impact the ability of these natural barriers to isolate waste will be included on the quality activities list.

The DOE intends to conduct activities in such a manner as to limit adverse effects on the long-term performance of the repository. Section 8.4 presents evaluations of the potential impacts of planned site characterization and construction activities on the waste isolation integrity of the

site. These evaluations indicate that some activities, if not performed in a controlled fashion, may alter the physical or chemical properties of the natural barriers in an adverse way. The activities listed below, are included on the preliminary quality activities list based on these evaluations.

Some of the major activities listed below include several tasks, all of which may not be considered to have the potential to adversely impact the natural barriers. These activities are indicated with an asterisk. For these activities, those parts of the activity that may potentially impact the ability of the natural barriers to perform their intended function will be controlled under a 10 CFR Part 60 Subpart G QA program. The intent of such a designation is to avoid requiring, for example, unnecessary controls on procurement of a backhoe to be used for a surface excavation activity, if procurement of such equipment has no impact on the conduct of the activity relative to impacting waste isolation. It is planned that individual parts of an activity that may adversely impact the natural barriers will be specifically identified in study plans, in design basis reports, or in plans for design-related testing at the site.

Based on the above discussion, the following major activities that may adversely affect a natural barriers ability to isolate waste are included on the preliminary quality activities list.

1. *All drilling and mining through the natural barriers within the controlled area that may adversely affect the natural barriers within the controlled area.

2. Monitoring the amount and composition of fluids introduced to the natural barriers within the controlled area, or that may adversely impact natural barriers within the controlled area, including surface fluids and fluid use and monitoring in ESF during construction and operation.

3. *Surface excavations in the controlled area.

4. *Blasting in the ESF.

5. *Materials use and monitoring in ESF during construction and operation.

6. *Ground support in ESF.

## 8.6.5 ADMINISTRATIVE QUALITY ASSURANCE PROCEDURES

The Project quality assurance plan (QAP) directs each participating organization in the Project to prepare quality assurance administrative procedures (QAAPs) to control their activities affecting quality. QAAPs are those procedures that define and direct controls and control systems making up the Project quality assurance program. Table 8.6-2 identifies the criteria by which the procedures are organized. Tables 8.6-3 through 8.6-20 list each Project participant's QAAPs under the criterion that it implements.

Table 8.6-2. Identification of quality assurance program plan criteria

| Criterion | Subject |
|---|---|
| 1.0 | Organization |
| 2.0 | Quality assurance program |
| 3.0 | Scientific investigation and design control |
| 4.0 | Procurement document control |
| 5.0 | Instruction, procedures, plans, and drawings |
| 6.0 | Document control |
| 7.0 | Control of prepurchased items and services |
| 8.0 | Identification and control of items |
| 9.0 | Control of processes |
| 10.0 | Inspection |
| 11.0 | Test control |
| 12.0 | Control of measuring and test equipment |
| 13.0 | Handling, shipping, and storage |
| 14.0 | Inspection, test, and operating status |
| 15.0 | Control of nonconforming items |
| 16.0 | Corrective action |
| 17.0 | Quality assurance records |
| 18.0 | Audits |

Table 8.6-3. Procedures for criterion 1.0: Organization

| Organization | Procedure[a] |
|---|---|
| DOE/Yucca Mountain Project Office | QMP 01-01 - WMPO Organization<br>QMP 01-02 - Stop Work Order |
| Fenix & Scisson Inc. | QAP 1.1 - Organization |
| Holmes & Narver Inc. | QAGL 1.0 - Organization and Responsibilities of Quality Assurance Personnel |
| Reynolds Electrical and Engineering Co. | NQP 1.0 - Organization<br>NQP 1.1 - Resolution of Disputes |
| Lawrence Livermore National Laboratory | QP 1.0 - Organization |
| Los Alamos National Laboratory | To be developed |
| Sandia National Laboratories | QAP 01.03 - Procedure for Quality Related Work Stoppage |
| U.S. Geological Survey | QMPP-1.01 - Organization Procedure<br>QMP-1.02 - Stop Work Authority |

[a]WMPO = Waste Management Project Office. This office has been renamed the Yucca Mountain Project Office.

Table 8.6-4. Procedures for criterion 2.0: Quality assurance program

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-02-01 - Indoctrination and Training<br>QMP-02-02 - Quality and Certification of Auditors<br>QMP-2-03 - Management Assessment of the NNWSI Project QA Program<br>QMP-02-04 - Readiness Reviews<br>QMP-02-05 - QA Commitment to Outside Agencies<br>QMP-02-06 - Assignment of QA Levels<br>QMP-02-08 - Technical Assessment Reviews |
| Fenix & Scisson Inc. | QAP 2.1 - QA Program |
| Holmes & Narver Inc. | QAGL 2.0 - Orientation and Training |
| Reynolds Electrical and Engineering Co. | NQP 2.0 - QA program<br>NQP 2.1 - Quality of Inspection Personnel<br>NQP 2.2 - Personnel Certification - QA Activity |
| Lawrence Livermore National Laboratory | QP 2.0 - Assurance<br>QP 2.1 Review and Approval of QA Requirements and Procedures<br>QA 20.0 - Assigning Levels of Quality Assurance<br>QP 21A.0 - Training<br>QP 21B0 - Qualification of personnel<br>QP 21B.1 - Requirements for the Qualification of Nondestructive Examination Personnel |
| Los Alamos National Laboratory | 02.1 - NNWSI[a] personnel Selection, Certification, and Training<br>02.2 - Assignment of QA Levels<br>02.3 - Quality Conflict Resolution<br>02.4 - Qualification of Old Data or Data Not Generated Under the NNWSI Program<br>02.5 - Training Procedure |

Table 8.6-4. Procedures for criterion 2.0: Quality assurance program (continued)

| Organization | Procedure[a] |
|---|---|
| Sandia National Laboratories | QAP 02-03 - QA Level Determination and Assignment<br>DOP 02-04 - Analysis Control and Verification<br>QAP 02-05 - Training and Familiarization Program<br>DOP 02-06 - Certification of Project Personnel<br>QAP 02-07 - Certification of Quality Assurance Auditors |
| U.S. Geological Survey | QMPP-2.01 - Management Assessment of the NNWSI-USGS Quality Assurance Program<br>QMPP-2.02 - Indoctrination and Training<br>QMPP-2.03 - Certification of USGS and USGS Contractor Personnel for the NNWSI Project<br>QMPP-2.05 - Qualification of QA Program Audit Personnel |

[a]NNWSI = Nevada Nuclear Waste Storage Investigations (Project). The Project has been renamed the Yucca Mountain Project.

Table 8.6-5. Procedures for criterion 3.0: Scientific investigation and design control

| Organization | Procedure[a] |
|---|---|
| DOE/Yucca Mountain Project Office | QMP 03-01 - Peer Review<br>QMP 03-02 - Scientific Investigation Control<br>QMP 03-03 - Use and Control of computer Programs<br>QMP 03-04 - Software Development and Maintenance<br>QMP 03-06 - Verification and Validation of Computer Programs |
| Fenix & Scisson Inc. | QAP 3.1 - Engineering Drawings<br>QAP 3.2 - Engineering Specifications |
| Holmes & Narver Inc. | QAGL 3. 0 - Drawing and Specification Review |
| Reynolds Electrical and Engineering Co. | NQP 3.0 - Design Control<br>NQP 3.1 Design/Review |
| Lawrence Livermore National Laboratory | QP 3A.0 - Scientific Investigation Control<br>QP 3A.1 - Scientific Investigation Test Control<br>QP 3B.0 - Design Control<br>QP 19.0 - Software Quality Assurance<br>QP 22.0 - Technical Review of Publications<br>QP 17.7 - Acceptance of Data Not Generated Under the Control of the NWMP QAPP<br>QP 19.1 (EQ3/6) - Appendix 1<br>QP 19.1 (EQ3/6) - Appendix 2<br>QP 19.1 (EQ3/6) Requirements for Development and use of Scientific and Engineering Software<br>QP 19.2 (EQ3/6) - Coding Standards for Fortran Computer Codes<br>QP 19.3 (EQ3/6) - Acquisition and Evaluation of Computer Codes<br>QP 19.4 (EQ3/6) - Development of Computer Codes<br>QP 19.5 (EQ3/6) - Verification and Validation of Computer Codes<br>QP 19.6 (EQ3/6) - Documentation of Scientific and Engineering Software |

Table 8.6-5. Procedures for criterion 3.0: Scientific investigation and design control (continued)

| Organization | Procedure[a] |
|---|---|
| Lawrence Livermore National Laboratory (continued) | QP 19.7 (EQ3/6) - Peer Review of Scientific and Engineering Software<br>QP 19.8 (EQ3/6) - Transfer of Computer Codes<br>QP 19.9 (EQ3/6) - Application of Scientific and Engineering Software<br>QP 19.10 (EQ3/6) - Error Reporting and Resolution<br>QP 19.11 (EQ3/6) - Working Environment for Storage, Development, and Application of Computer Codes<br>QP 19.12 (EQ3/6) - Backup and Archiving of Computer Codes |
| Los Alamos National Laboratory | 03.1 - Research and Development<br>03.2 - Technical Review of Publications<br>03.3 - Interface Control, IDS (CAR #016) |
| Sandia National Laboratories | DOP 02-01 - Requirements for Task Definition Statements<br>DOP 02-02 - Study Plan Requirements<br>DOP 03-01 - Reviewing, Approving, and Issuing NNWSI Engineering Drawings<br>DOP 03-02 - Software Quality Assurance Requirements<br>DOP 03-03 - Analysis Definition Requirements (new title)<br>DOP 03-04 - Design Investigation Control<br>DOP 03-05 - Design Control and Verification<br>DOP 03-06 - Design Change Control<br>DOP 03-07 - Technical Data Base Requirements<br>DOP 03-09 - SNL Interface Controls of Engineering Design<br>DOP 03-10 - NNWSI Routine Design Calculations |
| U.S. Geological Survey | QMP-3.01 - Identification of Research/ Experimental Activities<br>QMP-3.02 - USGS QA Level Assignment<br>QMP-3.03 - Scientific and Engineering Software QA |

Table 8.6-5. Procedures for criterion 3.0: Scientific investigation and design control (continued)

| Organization | Procedure[a] |
|---|---|
| U.S. Geological Survey (continued) | QMP-3.04 - Technical Review of NNWSI-USGS Publications<br>QMP-3.05 - Work Requests for NTS Contractor Services<br>QMP-3.06 - Scientific Investigation Plan<br>QMP-3.07 - Technical Review Procedure<br>QMP-17.02 - Acceptance of Data not Developed under the NNWSI QA Plan |

[a]NNWSI = Nevada Nuclear Waste Storage Investigations (Project). The Project has been renamed the Yucca Mountain Project.

Table 8.6-6. Procedures for criterion 4.0: Procurement document control

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-04-01 Procurement Document Control |
| Fenix & Scisson Inc. | To be developed |
| Holmes & Narver Inc. | To be developed |
| Reynolds Electrical and Engineering Co. | NQP 4.0 - Procurement Control and Documentation |
| Lawrence Livermore National Laboratory | QP 4.0 - Procurement Control and Documentation |
| Los Alamos National Laboratory | 04.1 - Procurement<br>04.2 - Acceptance of Procured Services<br>04.3 - Qualification of Suppliers |
| Sandia National Laboratories | DOP 04-01 - Procurement Document Requirements<br>DOP 04-02 - Changes to Procurement Documents |
| U.S. Geological Survey | QMP-4.01 - Procurement Document Control |

Table 8.6-7. Procedures for criterion 5.0: Instructions, procedures, plans and drawings

| Organization | Procedure[a,b] |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-05-01 Preparation and Control of Quality Management Procedures<br>QMP-05-02 - Preparation and Control of Branch Technical Procedures<br>QMP-05-03 Preparation and Control of the NNWSI Project QAP and the WMPO QAPP |
| Fenix & Scisson Inc. | QAP-5.1 - Preparation of Quality Assurance Procedures |
| Holmes & Narver Inc. | QAGL 5.0 - Generation and Control of Quality Assurance Guidelines |
| Reynolds Electrical and Engineering Co. | NQP 5.0 - Instructions, Procedures, Drawings<br>NQP 5.1 - Procedure Review |
| Lawrence Livermore National Laboratory | QP 5.0 - Instructions, Procedures, and Drawings<br>QP 5.1 - Preparation of Technical Procedures |
| Los Alamos National Laboratory | 05.1 - Preparation of Quality Administrative Procedures<br>05.2 - Preparation of Detailed Technical Procedures |
| Sandia National Laboratories | DOP 05-01 - Quality Assurance Procedure Requirements<br>DOP 05-02 - Technical Procedures Requirements<br>DOP - 05-03 - QA Review of DOPs |

Table 8.6-7. Procedures for criterion 5.0: Instructions, procedures, plans and drawings (continued)

| Organization | Procedure[a,b] |
|---|---|
| U.S. Geological Survey | QMP-5.01 - Preparation of Technical Procedures<br>QMP-5.02 - Preparation and Control of Drawings and Sketches<br>QMP-5.03 - Participant control of the USGS QAPP and QMPs<br>QMP-11.01 - Preparation and Issuance of Tentative Technical Procedures |

[a]WMPO = Waste Management Project Office. This office has been renamed the Yucca Mountain Project Office.

[b]NNWSI = Nevada Nuclear Waste Storage Investigations (Project). The Project has been renamed the Yucca Mountain Project.

Table 8.6-8. Procedures for criterion 6.0: Document control

| Organization | Procedure[a] |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-06-02 - Document Control<br>QMP-06-03 - Document Review and Approval |
| Fenix & Scisson Inc. | QAP 5.1 - Preparation of Quality Assurance Procedures<br>QAP 2.1 - QA Program<br>QAP 10.1 - Source Surveillance |
| Holmes & Narver Inc. | QAGL 6.0 - Generation and Control of Quality Assurance Guidelines |
| Reynolds Electrical and Engineering Co. | NQP 6.0 - Document Control |
| Lawrence Livermore National Laboratory | QP 6.0 - Document Control<br>QP 6.1 - Issue of Controlled Documents |
| Los Alamos National Laboratory | 06.1 - Document Control |
| Sandia National Laboratories | DOP 06-01 - Document Control System<br>DOP 06-02 - Procedure for Reviewing, Approving, and Issuing NNWSI Technical Information |
| U.S. Geological Survey | QMP-6.01 - Document Control |

[a]NNWSI = Nevada Nuclear Waste Storage Investigations (Project). The Project has been renamed the Yucca Mountain Project.

Table 8.6-9. Procedures for criterion 7.0: Control of prepurchased item and services

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-07-02 - Effectiveness of Participant QA Programs<br>QMP-07-03 - Control of Purchased Materials and Services<br>QMP-07-04 - Supplied Surveys |
| Fenix & Scisson Inc. | To be developed |
| Holmes & Narver Inc. | To be developed |
| Reynolds Electrical and Engineering Co. | NQP 7.0 - Control of Purchased Items and Services<br>NQP 7.2 - Procedure Document Review<br>NQP 7.3 - Supplier Evaluation<br>NQP 7.4 - Annual Supplier Evaluation |
| Lawrence Livermore National Laboratory | QP 7.0 - Procurement Control and Documentation |
| Los Alamos National Laboratory | To be developed |
| Sandia National Laboratories | DOP 07-01 - Planning of Procurements<br>DOP 07-02 - Evaluation for Acceptance of Purchased Items and Services<br>DOP 07-03 - Evaluation of Contractor QA Programs |
| U.S. Geological Survey | QMP-7.01 - Certification of Suppliers<br>QMP-7.02 - Receiving Inspection<br>QMP-7.03 - Acceptance of Materials, Equipment and Services |

Table 8.6-10. Procedures for criterion 8.0: Identification and control of items

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | Not applicable[b] |
| Fenix & Scisson Inc. | To be developed |
| Holmes & Narver Inc. | QAGL 2.0 - Identification and Control of Material, Parts and Services |
| Reynolds Electrical and Engineering Co. | NQP 8.0 - Identification and Control |
| Lawrence Livermore National Laboratory | QP 8.0 - Identification and Control of Materials, Parts and Components |
| Los Alamos National Laboratory | 08.1 - Identification and Control of Samples |
| Sandia National Laboratories | DOP 08-01 - Sample Identification and Handling Requirements<br>DOP 08-02 - Quality Assurance Procedure for Operation of the NNWSI[a] Core Library |
| U.S. Geological Survey | QMP-8.01 - Identification and Control of Geological and Hydrological Samples |

[a]NNWSI = Nevada Nuclear Waste Storage Investigations (Project). The Project has been renamed the Yucca Mountain Project.

[b]In accordance with the discussion on p.8.6-4, the DOE is currently reevaluating the applicability of this criterion.

Table 8.6-11. Procedures for criterion 9.0: Control of processes

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | Not applicable[a] |
| Fenix & Scission Inc. | To be developed |
| Holmes & Narver Inc. | QAGL 9.0 - Control and Special Processes |
| Reynolds Electrical and Engineering Co. | NQP 9.0 - Control of Processes<br>NQP 9.1 - Welder Qualification Procedure<br>NQP 9.2 - Welder Certification |
| Lawrence Livermore National Laboratory | QP 9.0 - Control of Processes |
| Los Alamos National Laboratory | Not applicable[a] |
| Sandia National Laboratories | DOP 09-01 - Control of Special Processes |
| U.S. Geological Survey | Not applicable[a] |

[a]In accordance with the discussion on p.8.6-4, the DOE is currently reevaluating the applicability of this criterion.

Table 8.6-12. Procedures for criterion 10.0: Inspection

| Organization | Procedure |
| --- | --- |
| DOE/Yucca Mountain Project Office | To be developed |
| Fenix & Scisson Inc. | QAP 10.1 - Source Surveillance<br>QAP 10.2 - Quality Assurance Surveillance of Neutron Hole Drilling Program |
| Holmes & Narver Inc. | QAGL 10.0 - Inspection |
| Reynolds Electrical and Engineering Co. | NQP 10.0 - Inspection<br>NQP 10.1 - Surveillance |
| Lawrence Livermore National Laboratory | QP 10.0 - Inspection |
| Los Alamos National Laboratory | To be developed |
| Sandia National Laboratories | QAP 10-01 - Surveillance Requirements<br>QAP 10-02 - Inspection |
| U.S. Geological Survey | QMP-10.01 - Inspection (Surveillance) |

Table 8.6-13. Procedures for criterion 11.0: Test control

| Organization | Procedure |
| --- | --- |
| DOE/Yucca Mountain Project Office | Not applicable[a] |
| Fenix & Scisson Inc. | Not applicable[a] |
| Holmes & Narver Inc. | To be developed |
| Reynolds Electrical and Engineering Co. | NQP 11.0 - Test Control |
| Lawrence Livermore National Laboratory | QP 11.0 - Test Control of Engineered Items |
| Los Alamos National Laboratory | Not applicable[a] |
| Sandia National Laboratories | DQP 11-01 - Experiment Procedure Requirements<br>DQP 11-02 - Requirements for Experiment/Test Logbooks<br>DQP 11-03 - Data Records Management System Interaction<br>DQP 11-05 - Analysis of Data Gathered in Experiments or Equipment Tests |
| U.S. Geological Survey | Not applicable[a] |

[a]In accordance with the discussion on p.8.6-4, the DOE is currently reevaluating the applicability of this criterion.

Table 8.6-14. Procedures for criterion 12.0: Control of measuring and test equipment

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | To be developed |
| Fenix & Scisson Inc. | QAP 12.1 - Control of Measuring and Test Equipment |
| Holmes & Narver Inc. | QAGL 12-0 - Control of Measuring and Test Equipment |
| Reynolds Electrical and Engineering Co. | NQP 12.0 - Control of Measuring and Test Equipment |
| Lawrence Livermore National Laboratory | QP 12.0 - Control of Measuring and Test Equipment |
| Los Alamos National Laboratory | 12.1 - Measuring and Test Equipment Calibration |
| Sandia National Laboratories | DQP 12.01 - Calibration Program |
| U.S. Geological Survey | QMP-12.01 - Instrument Calibration |

Table 8.6-15. Procedures for criterion 13.0: Handling, shipping and storage

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | To be developed |
| Fenix & Scisson Inc. | Not applicable[a] |
| Holmes & Narver Inc. | QAGL 13.0 - Handling, Storage and Shipping |
| Reynolds Electrical and Engineering Co. | NQP 13.0 - Handling, Shipping and Storage |
| Lawrence Livermore National Laboratory | QP 13.0 - Handling, Storage and Shipment |
| Los Alamos National Laboratory | DOP 13.1 - Handling, Shipping, and Storage |
| Sandia National Laboratories | DOP 13-01 - Identification, Handling, Shipping, and Storage Procedures for Items |
| U.S. Geological Survey | QMP-13.01 - Handling, Storage, & Shipping of Instruments |

[a]In accordance with the discussion on p.8.6-4, the DOE is currently reevaluating the applicability of this criterion.

Table 8.6-16. Procedures for criterion 14.0: Inspection, test and operating status

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | Not applicable[a] |
| Fenix & Scisson Inc. | Not applicable[a] |
| Holmes & Narver Inc. | QAGL 14.0 - Inspection, Test and Operating Status |
| Reynolds Electrical and Engineering Co. | NQP 14.0 - Inspection, Test and Operating Status |
| Lawrence Livermore National Laboratory | QP 14.0 - Inspection, Test and Operating Status |
| Los Alamos National Laboratory | Not applicable[a] |
| Sandia National Laboratories | DOP 14-01 - Status Indication of Items |
| U.S. Geological Survey | Not applicable[a] |

[a]In accordance with the discussion on p.8.6-4, the DOE is currently reevaluating the applicability of this criterion.

Table 8.6-17. Procedures for criterion 15.0: Control of nonconforming items

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-15-01 - Nonconformance Control<br>QMP-15-02 - Unusual Occurrence Reporting |
| Fenix & Scisson Inc. | QAP 15.2 - Control of Nonconforming Items<br>QAP 15.3 - Unusual Occurrence Reporting |
| Holmes & Narver Inc. | QAGL 15.0 - Nonconformances |
| Reynolds Electrical and Engineering Co. | NQP 15.0 - Control of Nonconformance Items |
| Lawrence Livermore National Laboratory | QP 15.0 - Nonconforming Items, Procedural Nonconformances and Conditions Adverse to Quality |
| Los Alamos National Laboratory | 15.1 - Nonconformances |
| Sandia National Laboratories | QAP 15-01 - Nonconformance Reporting and Controls |
| U.S. Geological Survey | QMP-15.01 - Control of Nonconforming Items<br>QMP-15.02 - Control of Unusual Occurrences |

Table 8.6-18. Procedures for criterion 16.0: Corrective action

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-16-01 - Corrective Action<br>QMP-16-02 - Trend Analysis<br>QMP-16-03 - Deficiency Reporting |
| Fenix & Scisson Inc. | QAP 16.1 - Corrective Action Requests<br>QAP 16.3 - Trend Analysis |
| Holmes & Narver Inc. | QAGL 16.0 - Corrective Action<br>QAGL 16.2 - Review of Nonconforming Documentation |
| Reynolds Electrical and Engineering Co. | NQP 16.0 - Corrective Action<br>NQP 16.1 - Request for Corrective Action |
| Lawrence Livermore National Laboratory | QP 16.0 - Corrective Action |
| Los Alamos National Laboratory | 16.1 - Corrective Action |
| Sandia National Laboratories | QAP 16-01 - Corrective Action Requirements |
| U.S. Geological Survey | QMP-16.01 - Control for Corrective Action Procedure |

Table 8.6-19. Procedures for criterion 17.0: Quality assurance records

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-17-01 - QA Records |
| Fenix & Scisson Inc. | QAP-DC-07 - Development of Technical Specifications |
| Holmes & Narver Inc. | QAGL 17.0 - QA Records |
| Reynolds Electrical and Engineering Co. | NQP 17.0 - QA Records |
| Lawrence Livermore National Laboratory | QP 17.0 - Quality Assurance Records<br>QP 17.1 - Receipt and Review of Quality Assurance Records<br>QP 17.2 - Identification and Review of Quality Assurance Records<br>QP 17.3 - Storage of Quality Assurance Records<br>QP 17.4 - Transmittal of Quality Assurance Records |
| Los Alamos National Laboratory | DOP 17.1 - Records Management Control |
| Sandia National Laboratories | DOP 17-01 - Records Management<br>DOP 17-02 - DRMS Operation |
| U.S. Geological Survey | QMP-17.01 - QA Records Management |

Table 8.6-20. Procedures for criterion 18.0: Audits

| Organization | Procedure |
|---|---|
| DOE/Yucca Mountain Project Office | QMP-18-01 - Audits<br>QMP-18-02 - Surveillance |
| Fenix & Scisson Inc. | QAP 18.1 - Audits<br>QAP 16.2 - Deficiency Reporting<br>QAP 18.3 - Surveillance |
| Holmes & Narver Inc. | QAGL 18.0 - Audits<br>QAGL 18.1 - Qualification of Audit Personnel<br>QAGL 18.2 - Surveillance Activities |
| Reynolds Electrical and Engineering Co. | NQP 18.0 - Audits<br>NQP 18.1 - Qualification and Certification of Audit Personnel |
| Lawrence Livermore National Laboratory | QP 18.0 - Audits<br>QP 18.1 - Surveillance Procedures<br>QP 18.2 - Qualification of Quality Assurance Audit Personnel |
| Los Alamos National Laboratory | 18.1 - Audits<br>18.2 - Surveys |
| Sandia National Laboratories | QAP 18-01 - Audit Requirements |
| U.S. Geological Survey | QMP-18.01 - External and Internal Auditing |

The applicability of criteria and the procedures identified in the tables are expected to change (e.g., due to implementation of a fully qualified QA program; as new procedures are identified; as the scope of work of participants changes). Where criteria have been identified to apply to an organization, but the procedures have not yet been developed, the procedure is listed as "to be developed" in the tables. Where criteria have been identified as not applicable, the applicability will be reevaluated as the DOE revises existing methodology to ensure consistency with NRC (1988b), as described on pg. 8.6-4. Additional justification for the applicability of criteria to participants will be described in the participant QA program plans. The latest approved and issued revisions of the documents will be applied during site characterization. Semiannual progress reports will highlight any changes to the tables.

## 8.6.6 DETAILED TECHNICAL PROCEDURES AND TEST PLANS

The Project QAP (DOE, 1988c) describes two methods for documentation and control of scientific work associated with individual technical activities conducted during site characterization. These are the scientific notebook system and the technical implementing procedure system. The scientific notebook system will generally be used by qualified individuals who are using a high degree of professional judgment or trial and error methods, or both, in their work. Alternatively, the technical implementing procedure system will generally be used when qualified technicians are performing repetitive work that does not include the use of professional judgment or trial and error methods in the performance of the work. Detailed technical implementing procedures are required when it is not possible to deviate from a strict sequence of actions without endangering the validity of the results that will be obtained from the work.

Section 8.3.1 describes the site characterization activities that will be controlled by test and implementation procedures or scientific notebooks. Technical implementing procedures that are not yet available will be identified in future semiannual progress reports and developed, approved, and issued before testing begins. Detailed plans for site characterization testing will be provided in study plans.

*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

*Volume VIII, Part B*

*Chapter 8, Section 8.7, Decontamination and Decommissioning*

*December 1988*

*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

# 8.7 DECONTAMINATION AND DECOMMISSIONING

The Nuclear Waste Policy Act, as amended (NWPAA, 1987), directs the U.S. Department of Energy (DOE) to prepare plans for the decontamination and decommissioning of the Yucca Mountain site in the event that the site is determined to be unsuitable for development as a repository, and further requires the DOE to mitigate any significant adverse environmental impacts caused by site characterization activities. As set forth in the Mission Plan (DOE, 1987d), the overall objective of decontamination, decommissioning, and mitigation activities is to return areas disturbed by site characterization activities to their original condition, to the maximum extent practicable. These activities would be conducted in compliance with all applicable Federal, State, and local laws and regulations.

As described in previous sections of this SCP, site characterization activities, for the most part, would be similar to the types of activities typical of large construction projects. Impacts caused by such projects, and expected from site characterization, are usually limited to land disturbance and are routinely mitigated by a variety of accepted restoration practices. These impacts would be minimized or avoided, to a large extent, by the adoption of standard operating procedures and good engineering practices. In addition, a plan will be developed for monitoring and minimizing of potentially significant adverse environmental impacts. The success of standard operating procedures, good engineering practices, and monitoring and mitigation activities will serve to minimize the extent to which surface areas are disturbed and thereby help to minimize the extent of decommissioning that will be needed at the Yucca Mountain site.

This section presents general plans for decontamination and decommissioning of the Yucca Mountain site and for mitigation of any significant adverse environmental impacts that may be caused by site characterization. Detailed plans for these activities would be prepared as necessary and in consultation with the appropriate Federal and State agencies and any affected Indian Tribes. A reclamation program plan, reclamation implementation plan, and reclamation feasibility plan will be prepared to describe various aspects of the decommissioning and restoration of the Yucca Mountain site. The reclamation program plan will detail policy issues, the reclamation implementation plan will provide detailed descriptions of the types of procedures to be used in decommissioning-related activities, and the reclamation feasibility plan will describe site-specific studies to evaluate feasibility of reclamation practices at the Yucca Mountain site. Before initiating surface disturbing activities, site-specific reclamation guidelines will be developed.

Since some site characterization activities would occur on lands administered by the Bureau of Land Management (BLM) (including the Nellis Air Force Base Range), consultations with this agency with regard to decommissioning and mitigation would be required. To obtain access to BLM land, a right-of-way plan of development was submitted to and approved by the BLM, as required by the Federal Land Policy and Management Act. This plan of development contains plans to minimize impacts and to stabilize and rehabilitate the site after site characterization activities are terminated. Elements of the right-of-way plan are described in Section 8.7.2.

Decontamination of the site is discussed in Section 8.7.1 and general decommissioning plans are described in Section 8.7.2. Mitigation of any significant adverse environmental impacts that remain after decontamination and decommissioning activities are complete is discussed in Section 8.7.3.

### 8.7.1 DECONTAMINATION

The Nuclear Waste Policy Act, as amended, allows for the use of radioactive material during site characterization subject to approval by the Nuclear Regulatory Commission. However, current plans for site characterization activities do not include the use of radioactive tracers or high-level radioactive materials. Although no uncontained radioactive materials are planned to be used during site characterization, it is nevertheless quite common to use radioactive sources and sensors as geophysical logging tools to investigate the movement of ground water during exploratory drilling. These sources are designed to be fully contained and retrievable, as addressed in Chapter 4 of the environmental assessment for Yucca Mountain (DOE, 1986b). Since contained, retrievable geophysical logging tools are the only radioactive materials anticipated for use during site characterization, no decontamination is expected to be required after site characterization. Nevertheless, if other radioactive materials were used, plans for decontamination would be developed in consultation with appropriate Federal and State agencies.

### 8.7.2 DECOMMISSIONING

Decommissioning is defined as the planned, orderly execution of steps to place a facility in a permanently inoperable, safe condition and includes those activities used to return disturbed areas to their original condition. Decommissioning, as used here, includes the disassembly and removal of man-made materials from the site and the backfilling of excavated areas, as well as activities needed to stabilize and rehabilitate the area.

Decommissioning-related activities would occur in three phases: pre-decommissioning soil stabilization that would occur during site preparation and construction; decommissioning following abandonment or termination of sites; and post-decommissioning monitoring.

Pre-decommissioning soil stabilization procedures implemented prior to site development and during site use would protect against soil loss and provide wildlife habitats. These measures would include gathering information on soil depth and plant cover during preconstruction surveys, removing and stockpiling topsoil, installing or constructing erosion control devices prior to site development, and establishing vegetative cover over topsoil stockpiles where appropriate as soon as possible. Information collected during preconstruction surveys will be used to develop specific reclamation guidelines that will specify items such as location and amount of topsoil to be stockpiled.

Decommissioning of individual disturbed areas would commence after it was determined that they were no longer needed for the program. All wastes, including garbage, concrete, asphalt, equipment, pipes, drilling muds, sewage, excess excavated material, waste water, and chemical wastes, would be removed or stabilized on site in accordance with Federal and State standards as described in the Environmental Regulatory Compliance Plan. Soils from each area and the topsoil stockpile would be analyzed to determine the chemistry, nutrient levels, and concentration of chemical contaminants present. This information would be used to determine what treatments or amendments, if any, would be required to enable the soil to support plant growth. Next, soil compaction would be relieved through mechanical means such as ripping or disking. Excavated areas such as trenches, borrow pits, shafts, and drillholes would be backfilled and sealed as appropriate. The area would then be graded to approximately the original contours, and stockpiled topsoil would be redistributed to approximately its original depth. Topsoil would be harrowed to provide an adequate seedbed, and the area would be revegetated using the seed or seedlings of native or adapted species. A mulch may be applied, as necessary, to provide for soil stabilization and moisture retention.

The perimeter of each decommissioned area would be visibly marked. These areas would be visited periodically to monitor plant growth and animal use. Quantitative site monitoring will begin on the third spring after decommissioning and continue until the site is judged to be adequately restored.

If the Yucca Mountain site is deemed unsuitable for repository development, it is possible that, after consultation with the appropriate Federal and State agencies and any affected Indian Tribes, an alternative use for the facilities may be identified. If an alternative use for the exploratory shaft facility (ESF) is identified after site characterization is terminated, decommissioning activities would be limited to those areas not needed for future use of the facility. If no alternative use is identified, decommissioning of the entire site would begin as soon as practicable.

Section 8.7.2.1 discusses decommissioning in areas disturbed by surface-based activities; Section 8.7.2.2 discusses decommissioning of the ESF.

### 8.7.2.1 Decommissioning for surface-based activities

Surface-based activities are those site characterization activities that are not directly related to the ESF. These include activities such as surface trenches, drillholes, seismic surveys, and access roads. Decommissioning of individual areas affected by surface-based activities would occur after it was determined that these areas are no longer needed.

Trenches excavated for surficial geological investigations would be backfilled with material excavated during the trenching operation. The area would be graded to approximate the original contour of the land and reestablish natural drainage patterns. Stockpiled topsoil from the site would be replaced to approximately its original depth, and actions would be taken to revegetate the area and stabilize the soil.

Abandoned drillholes would be sealed as described in Section 8.3.3. The area would then be graded to approximate the original topography, stockpiled topsoil from the site would be replaced to its original depth, and efforts would be taken to stabilize the soil and revegetate the area.

Access roads that are no longer needed would be decommissioned. Decommissioning would entail removal of the road-surfacing material and disposal of this material in an approved landfill. The area would then be treated to relieve soil compaction (e.g., through mechanical ripping or disking); it would be regraded to approximate the original topography and restore natural drainage patterns; stockpiled topsoil from the site would be redistributed to approximately its original depth; and steps to stabilize the soil and revegetate the area would be taken. Temporary, unsurfaced access roads or off-road vehicle trails may require some decommissioning. This would probably be limited to disking or ripping the soil surface along the route in order to relieve soil compaction followed by stabilization and revegetation activities.

Other site characterization activities are planned that would disturb relatively small areas. These activities would include pavement studies, ponding studies, seismic lines, infiltration studies, etc. Decommissioning activities for these surface disturbances will be determined as appropriate to ensure adequate rehabilitation and soil stabilization.

#### 8.7.2.2 Decommissioning of the exploratory shaft facility

If it is determined that the Yucca Mountain site is unsuitable for a repository, it is possible that, after consultation with Federal and State agencies and any affected Indian Tribes, an alternative use for the exploratory shaft facility (ESF) may be identified. If a near-term use for the ESF is identified, the utilities and ventilation systems of the ESF would be left in place and periodic maintenance would preserve the structural integrity of the facility. Physical security (adequate to prevent accidents and unauthorized access) would be retained at the surface. Decommissioning of areas not needed for future use of the facility could occur as soon as practicable. If a long-term alternative use for the ESF is identified, a strategy to preserve the ESF for future use could be implemented. This strategy would entail the decommissioning of areas not needed for future use, removing the utilities and any salvageable materials from the interior of the facility, and welding steel covers over the openings to prevent accidents or unauthorized access. The sealed facility would then require only a minimum degree of security to protect the shafts from vandalism and prevent accidents.

If the Yucca Mountain site is deemed unsuitable for development of a repository, and if no alternative use for the site is found, the ESF site would be restored, to the maximum extent practicable, to its original condition. Decommissioning would proceed in accordance with all applicable Federal, State, and local regulations. Detailed decommissioning plans adopted by the DOE would be developed after consultation with the appropriate Federal and State agencies and any affected Indian Tribes.

Surface facilities at the ESF would be decommissioned by removing all structures and pads and stabilizing and rehabilitating the land. Facilities would be removed by the most practical and effective methods. Portable and prefabricated buildings would be emptied of their contents, dismantled, and removed from the site. Hoist equipment (including headframes), electric generators, electric and water distribution systems, ventilation equipment, meteorological towers, and communications equipment would also be removed from the site and salvaged. Shaft collars, drilling-related structures, and other foundations would be reduced to manageable pieces and trucked to appropriate disposal sites. Surfacing material for access roads, parking areas, and other paved or gravelled areas would be removed from the site and disposed of in an appropriate landfill. Fluid impoundments (e.g., mud-pits) would be backfilled after the removal and disposal of their contents. Borrow pits would also be backfilled. Buried water, electrical, and sewage lines would be disconnected below the surface and left in the ground.

Structures, equipment, pumps, and material-handling equipment would be removed from the shaft stations, underground drifts, and test rooms. Horizontal and vertical drillholes extending from the exploratory shaft and rooms would be sealed. Subsurface drifts and rooms would be backfilled with the material that was originally removed during excavation or with an engineered material. The exploratory shafts (ES-1 and ES-2) would be stripped of equipment and structures. The shaft liners would be left in place.

The shafts may be backfilled with the material that was removed during excavation and placed in the muck-storage area. This would minimize the amount of material to be stabilized or disposed of from the surface. Depending on the specific goals of shaft decommissioning, other backfill material could be used. For example, information from site characterization may dictate that a grout that matches the density of the various rock layers should be used, rather than material excavated from the shaft. Stockpiled excavated material that is not used to backfill shafts or other areas would be stabilized on site or removed from the site and disposed of in an appropriate landfill. Backfill material placed in the shaft(s) and underground drifts will be specifically designed and emplaced to prevent subsidence.

Once shafts are sealed, excavated areas are backfilled, and buildings and other surface structures or materials are removed, restoration of the site would proceed. Restoration activities would include regrading the area to approximate the original topography of the area and restore natural drainages; ripping or disking areas where soil compaction is significant (e.g., access routes, parking areas); redistributing stockpiled topsoil to approximately its original depth; stabilizing the soil and adding amendments, if necessary; and revegetating the area with native or adapted plants. Details of these restoration plans would be developed later in accordance with the specific needs of the program and after consultation with appropriate Federal and State agencies and any affected Indian Tribes.

## 8.7.3 PLANS FOR MITIGATION OF ANY SIGNIFICANT ADVERSE IMPACTS CAUSED BY SITE CHARACTERIZATION ACTIVITIES

It was determined in Chapter 4 of the Yucca Mountain environmental assessment (DOE, 1986b) that conducting site characterization activities at Yucca Mountain would not result in significant adverse environmental impacts. The environmental assessment listed standard operating procedures and good engineering practices (e.g., avoiding or minimizing construction in environmentally sensitive areas such as steep slopes or watercourses) that would reduce the potential for any significant adverse environmental impact. In addition, the DOE has agreed to work with the State and any affected Indian Tribes to monitor the effects of certain site characterization activities and to develop mitigation measures if any significant adverse impacts appear likely to occur. These environmental monitoring activities will be described in a plan for environmental monitoring and mitigation. Implementation of a plan for standard operating procedures, good engineering practices, the monitoring and mitigation plan, and the decommissioning activities described above should eliminate the need for further mitigation. However, should any significant adverse environmental impacts remain after the above preventative steps have been taken, specific mitigation plans would be developed in consultation with appropriate Federal and State agencies.

## 8.7.4 SUMMARY

This section presented general plans for decontamination and decommissioning of the Yucca Mountain site, should it be deemed unsuitable for repository development, and for mitigation of any significant adverse environmental impacts that may be caused by site characterization. Currently, decontamination and mitigation efforts beyond standard operating procedures, good engineering practices, monitoring and mitigation activities, and decommissioning activities are not expected to be needed, and this section described the types of activities planned for decommissioning. Detailed plans for these activities would be prepared when the extent of work needed is better known and only after consultation with the appropriate Federal and State agencies. Preconstruction reclamation guidelines will be incorporated into site preparation plans and will guide reclamation and decommissioning to the extent practicable at the time surface disturbing activities are initiated.

*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

*Volume VIII, Part B*

*Chapter 8 References*

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*Office of Civilian Radioactive Waste Management*

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*Nuclear Waste Policy Act*
*(Section 113)*

# Site Characterization Plan

*Yucca Mountain Site, Nevada Research and Development Area, Nevada*

## *Volume VIII, Part B*

*Glossary and Acronyms*

*December 1988*

*U. S. Department of Energy*
*Office of Civilian Radioactive Waste Management*

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# GLOSSARY

Definitions in this glossary reflect the usage of words and terms in the Yucca Mountain Site Characterization Plan (SCP). These definitions may or may not be used in the same way in other circumstances.

| | |
|---|---|
| A horizon | The uppermost zone in the soil profile from which soluble salts and colloids have been leached and in which organic matter has accumulated. |
| abnormal | Describes events or conditions that do not occur on a routine basis or that are not expected during normal operations; also describes materials that are not handled routinely, such as experimental spent fuel. |
| absorbed radiation dose | A measure of the amount of energy deposited by ionizing radiation in a given mass of absorbing medium. The unit of absorbed radiation is the rad. |
| accelerometer | A motion detector whose response is linearly proportional to the acceleration of the earth materials with which it is in contact. |
| access drift | A drift that connects the mains and the perimeter drifts; it delineates the waste emplacement panels and provides access to the waste emplacement drifts. In the vertical waste emplacement configuration, there is also a midpanel access drift that supplies additional ventilation to the more numerous drifts. |
| accessible environment | (1) The atmosphere, (2) land surfaces, (3) surface waters, (4) oceans, and (5) all of the lithosphere that is beyond the controlled area. |
| accessory mineral | A mineral whose presence in a rock is not essential to the proper classification of the rock. Accessory minerals generally occur in minor amounts typically less than 1 weight percent; in sedimentary rocks they are mostly heavy minerals. |
| accidental radiological releases | Releases of radioactivity that deviate from the planned or expected behavior or course of events in connection with the operation of the facility and that have environmental protection or safety significance. |
| accretionary boundary | A boundary between two plates that are moving apart, with new oceanic-type lithosphere being created at the seam. |
| acidic | A descriptive term applied to those igneous rocks that contain more than 66 percent $SiO_2$. |

| | |
|---|---|
| acoustic velocity log | Generic term for a well log that displays any of several measurements of acoustic waves in rocks exposed in a borehole. |
| actinides | Radioactive elements in the series beginning with atomic number 89 and continuing through 103. |
| activation products | The group of radionuclides that are formed as a result of neutron capture by chemical elements present in the fuel assembly hardware and fuel rod cladding. |
| active institutional controls | Controls instituted by a government to guard a repository against intrusion and to perform monitoring or maintenance operations. |
| actual retrieval period | The time required to retrieve the emplaced waste from the underground facility. For design purposes, this period is 34 years. |
| adsorption | The condensation of gases, liquids, or dissolved substances or solids. |
| advanced conceptual design (ACD) | The design phase that will be used to explore selected design alternatives and will firmly fix and refine the design criteria and concepts to be made final in later design efforts. The project feasibility will be demonstrated, life-cycle costs estimated, preliminary drawings prepared, and a construction schedule developed as required by U.S. Department of Energy Order 6410.1. |
| advection | The movement of dissolved solids by ground-water flow. |
| advertent human intrusion | Intentional intrusion or entry into the repository for purposes of waste retrieval or other disposal-related materials (i.e., canister materials). |
| aeromagnetic survey | A magnetic survey made with an airborne magnetometer from a moving aircraft. |
| aftershock | An earthquake that follows a larger earthquake or main shock and originates at or near the focus of the larger earthquake. Generally, major earthquakes are followed by a large number of aftershocks that decrease in frequency over time. |
| affected area | Either the area of socioeconomic impact or the area of environmental impact. |

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|---|---|
| affected Indian Tribe | Any Indian Tribe (1) within whose reservation boundaries a repository for radioactive waste is proposed to be located or (2) whose federally defined possessory or usage rights to other lands outside the reservation's boundaries arising out of congressionally ratified treaties may be substantially and adversely affected by the locating of such a facility, <u>provided</u> that the Secretary of the Interior finds, upon the petition of the appropriate governmental officials of the Tribe, that such effects are both substantial and adverse to the Tribe. |
| affected State | Any State that (1) has been notified by the U.S. Department of Energy in accordance with Section 116(a) of the Nuclear Waste Policy Act of 1982 as containing a potentially acceptable site, (2) contains a candidate site for site characterization or repository development, or (3) contains a site selected for repository development. |
| aggradation | The process of building up a surface by deposition. |
| aging | Storage of radioactive materials, especially spent nuclear fuel, to permit the decay of short-lived radionuclides. |
| air-cored | A core drilled using only compressed air as the drilling fluid, rather than other drilling fluids such as air-foam or drilling mud. |
| air-fall tuff | See "ash-fall tuff." |
| air-foam method | A procedure for drilling wells into rock formations, wherein the well cuttings are returned to the ground surface in a mixture of compressed air and a chemical foaming agent. The method offers the advantage of using minimum drilling fluids, thus fluid migration into the rock formation is also minimized. |
| alkali flat | A level lake-like plain formed in a shallow depression where accumulated water evaporates depositing fine sediment, dissolved minerals, or efflorescent salts. |
| allochthonous | A term applied to rocks that have been transported to their present outcrop location by tectonic processes, as in a thrust sheet. |
| alluvial fan | A low, outspread, relatively flat to gently sloping mass of rock material shaped like an open fan or segment of a cone made by a stream where it runs out onto a level plain or meets a slower stream. The fans generally form where streams issue from mountains onto low land. |

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| alpha activity | See "alpha decay." |
| alpha decay | A radioactive transformation in which an alpha particle is emitted by a nuclide, thus changing one nuclide to another that has a lower atomic number and weight. |
| alpha particle | A positively charged particle emitted in the radioactive decay of certain nuclides. It is made up of two protons and two neutrons bound together, and it is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of radiation: alpha, beta, and gamma. |
| alpha spectrometry | A method of determining the type and concentration of certain radioactive isotopes by analysis of the alpha wave spectra that are emitted. |
| alteration (geologic) | Changes in the chemical or mineralogic composition of a rock, generally produced by weathering, hydrothermal solutions, or metamorphism. |
| altithermal | A period of high temperature, especially the postglacial thermal optimum. |
| ambient radiation monitoring | The measurement of the level of radiation present in the surrounding environment. |
| amplitude (of a fold) | For a symmetrical, periodic fold system the amplitude of a fold is analogous to the amplitude of a wave form, (i.e., half the original distance between the antiformal and synformal enveloping surfaces). |
| anelastic strain | Time-dependent, but eventually recoverable strain that occurs in a (anelastic) body after change in applied stress. |
| angle of internal friction | The angle between a resultant force acting on a plane of friction and the perpendicular line to that plane. |
| anion exclusion | The virtual exclusion of anions from pores between adjacent grains in a compacted clay-water system as a result of the solution between the pores being composed of overlapping diffuse layers. |
| antecedent moisture | The amount of moisture present in a soil mass at the beginning of a runoff period. |
| anticipated processes and events | Those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved. |
| anticline | A fold that is generally convex upward and the core of which contains stratigraphically older rocks. |

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| Antler orogeny | An orogeny that extensively deformed Paleozoic rocks of the Great Basin in Nevada during late Devonian and early Mississippian time. |
| aperture | The perpendicular distance separating the adjacent rock walls of an open discontinuity. |
| application | The act of making a finding of compliance or non-compliance with the qualifying or disqualifying conditions specified in the guidelines of Subparts C and D, in accordance with the types of findings defined in Appendix III of the guidelines (10 CFR 960). |
| aquefaction | The sudden large decrease of the shearing resistance of a cohesionless soil caused by the collapse of the structure by shock or strain and associated with a sudden but temporary increase of the pore fluid pressure. It involves temporary transformation of the material into a fluid mass. |
| aquifer | A formation, group of formations, or a part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. |
| aquitard | A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs but may serve as a storage unit for ground water. |
| areal power density (APD) | The concentration of thermal power produced by emplaced waste, which is averaged over the area of an emplacement panel and expressed in watts per square meter or in kilowatts per acre. The initial value (IAPD) at the time the waste is emplaced is a design input parameter used in far-field thermal and thermo-mechanical response calculations. |
| arid | A climate characterized by dryness. Variously defined as having precipitation amounts insufficient for plant life or for crops without irrigation. Arid regions have less than 25 cm (10 in.) of annual rain-fall or a higher evaporation rate than precipitation rate. |
| arroyo | A term applied in the arid and semiarid southwestern United States to a small, deep, flat-floored channel or gully of an ephemeral or intermittent stream. |
| articulation | The action or manner of jointing, or the state of being jointed. |

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| ash | Pyroclastic material less than 4.0 mm in diameter. This term refers to both unconsolidated detritus and the consolidated deposit. |
| ash-fall tuff | (1) A tuff deposited by volcanic ash settling out of the atmosphere and forming a blanketing deposit of relatively uniform thickness regardless of the underlying topography. (2) A deposit of volcanic ash resulting from such a fall and lying on the ground surface. |
| ash-flow tuff | A tuff deposited by a volcano-derived hot density current. It can be either welded or unwelded and often fills in channels making the thickness of the resulting deposit a function of the underlying topography. |
| as low as reasonably achievable (ALARA) | As low as reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, other societal and socioeconomic considerations, and the utilization of atomic energy in the public interest. |
| asthenosphere | A weak layer or shell of the earth below the lithosphere in which isostatic adjustments take place, mafic magmas may be generated, and seismic waves are strongly attenuated. |
| astronomic forcing | Variations in the earth's orbit that influence climate by changing the latitudinal and seasonal distribution of incoming solar radiation. |
| atmospheric stability class | An index that indicates the atmosphere's ability to disperse airborne releases. |
| atomic energy defense activity | Any activity of the Secretary of Energy performed in whole or in part in carrying out any of the following functions: Naval reactors development, weapons activities, verification and control technology, defense nuclear materials production, defense nuclear waste and materials by-products management, defense nuclear materials security and safeguards and security investigations, and defense research and development. |
| attenuation | (1) A reduction in the amplitude or energy of a signal, such as might be produced by passage through a filter. (2) A reduction in the amplitude of seismic waves, as produced by divergence, reflection and scattering, and absorption. |

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| Atterberg limits | In a sediment, the water-content boundaries between the semiliquid and plastic states (known as the liquid limit) and between the plastic and semisolid states (known as the plastic limit). |
| autecology | The study of the relationships between individual organisms or species. |
| authiclastic | A term applied to rocks that have been brecciated in place by mechanical processes. |
| authigenic | (1) Generated on the spot. (2) Pertaining to minerals formed on the spot where they are now found, before burial and consolidation of sediment. |
| autochthon | A body of rocks that remains at its site of origin, where it is rooted to its basement. Although not moved from their site, autochthonous rocks may be mildly to considerably deformed. |
| B horizon | Soil layer characterized by the secondary accumulation or enrichment of clay, iron, or aluminum, and by the development of distinctive structures not present in the parent material. |
| back-arc spreading | Sea-floor spreading center behind an island arc chain relative to a subduction boundary. |
| backfill | (1) The general fill that is placed in the excavated areas of the underground facility. Backfill materials may be either excavated tuff or other earthen materials. (2) The material or process used to refill an excavation. |
| background radiation | Radiation that is produced by sources other than the facility of specific interest, such as naturally occurring radioactive minerals in the earth, cosmic rays, naturally occurring radionuclides in living organisms, and fallout from weapons tests. |
| bacterial metabolites | An intermediary product of metabolism. |
| bailer | A long, hollow, steel cylindrical container or pipe with a valve at the bottom for admission of fluids, attached to a wire line and used in cable-tool drilling for recovering and removing water, cuttings, and mud from the bottom of a borehole. |
| bajada | A broad, gently inclined detrital surface extending from the base of a mountain range out into an inland basin formed by the lateral coalescence of a series of alluvial fans and having an undulating character. |

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| barometric efficiency | The ratio of the product of the change in hydraulic head and the specific weight of water to the change in atmospheric pressure. |
| barrier | Any material or structure that prevents or substantially delays movement of water or radionuclides. |
| base flow | Sustained or fair-weather flow of a stream, whether or not affected by the works of man. |
| base level | (1) The theoretical limit or lowest level toward which erosion of the earth's surface constantly progresses but seldom, if ever, reaches. (2) The level below which a stream cannot erode its bed. |
| Basin-Range faulting | Faulting characterized by normal (extensional) fault movements. Regional geologic structure dominated by generally subparallel fault-block mountains separated by broad alluvium-filled basins. |
| bearing strength | The maximum load per unit area that the ground can support without failing in shear or causing excessive settlement of the soil under imposed loads. |
| bench-scale testing | Testing of materials, methods, or chemical processes on a small scale, such as on a laboratory worktable. |
| benchmark | (1) Comparison of the results of one computer code with the results of another code designed to solve an identical problem to show that they produce similar results. The particular problem for which this comparison is made is called a "benchmark problem." (2) A relatively permanent metal tablet or other mark firmly embedded in a fixed object, indicating a precisely determined elevation. |
| beta particle | A negatively charged particle, physically identical with the electron, that is emitted by certain radionuclides. |
| beta radiation | See "beta particle." |
| bifurcating | The separation or branching of a stream into two parts. |
| binding constant | A measure of the affinity of a microorganism to an actinide. Analogous to a sorption coefficient. |
| biological half-life | The time required for an organism to eliminate half the amount of a radionuclide ingested or inhaled. |
| biosphere | The zone at and adjacent to the earth's surface where all life forms exist. |

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| blind-hole drilling | A technique for sinking shafts. It uses a multiple-cone bit with a diameter larger than 6 feet. |
| blocking temperature | The temperature at which the potassium-argon clock is reset for a specific mineral. |
| blooie line | A pipe or flexible tube that conducts air or other gas laden with cuttings from the collar of a borehole to a point far enough removed from the drill rig to keep air around the drill free from dust. |
| body-wave | A seismic wave that travels through the interior of the earth (or other geologic body) and that is not related to any boundary surface. A body wave may be either longitudinal (p-wave) or transverse (s-wave), depending on the direction of particle motion with respect to the direction of propagation and the direction of constant phase. |
| boiling water reactor (BWR) | A nuclear reactor system that uses boiling water in the primary cooling system. Steam from the primary cooling system turns turbines to generate electricity. |
| borehole | A hole made with a drill, auger, or other tools for exploring strata in search of minerals, supplying water for blasting, emplacing waste, proving the position of old workings or faults, or releasing accumulations of gas or water. Boreholes include core holes, dry-well-monitoring holes, waste-emplacement boreholes, and test holes for geophysical or ground-water characterization. |
| borehole deformation gauge | An instrument used to measure deformation or change in deformation of the wall of a borehole, in response to changes in applied stress in the volume of material containing the borehole. This phase typically is used in reference to a particular type of gauge developed by the U.S. Bureau of Mines (USBM), which measures the change in one or more diameters in response to overcoring of the borehole. The USBM borehole deformation gauge has also been used in relatively long-term monitoring applications. |
| borehole-flow survey | A survey using a device called a "spin flow meter," the purpose of which is to determine the vertical velocity of ground water within the well bore. |
| borehole geophysical method | A method for investigating geophysical rock mass responses and structure in situ by means of instruments lowered into one or more boreholes. See also: "borehole-to-borehole geophysical method," "crosshole geophysical method," and "borehole-to-surface geophysical method." |

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| borehole geophysical survey (directional survey) | Determination of the direction and deviation from the vertical of a borehole by precise measurements at various points along its central axis. Also, the record of information thus obtained. |
| borehole jacking | A test that measures in situ rock-mass deformation through the application of unidirectional pressures to the opposite sides of a borehole. |
| borehole-to-borehole geophysical method | A method for investigating geophysical rock mass responses and structure in situ by means of instruments lowered into adjacent boreholes. Electrical or seismic phenomena are propagated between the holes, yielding information about the intervening rock mass. |
| borehole-to-surface geophysical method | A method for investigating geophysical responses and structure in situ by means of instruments deployed in a borehole, and on the surface adjacent to the borehole. Electrical or seismic phenomena are propagated between the hole and the surface, yielding information about the intervening rock mass. |
| borescope | A straight-tube telescope with a mirror or prism used to visually inspect a cylindrical cavity. |
| borosilicate glass | A silicate glass containing at least five percent boric acid and used to solidify commercial or defense high-level waste. |
| borrow area | An area in which earth material (sand, gravel, etc.) is taken to be used for fill at another location. |
| Bouguer gravity | The observed value for gravitational acceleration at a point on the surface of the earth, corrected for latitude effects, elevation effects, the acceleration from a horizontal slab extending between the station elevation and the datum elevation (Bouguer correction), and the acceleration from the terrain around the station. |
| boundary element method | A method for modeling the behavior of continuous physical systems in which modeling segments are only defined along the boundary of the modeled region. |
| Bowen ratio | The ratio of heat loss by conduction to heat loss by evaporation. |
| branch corridor | A corridor that runs at an angle to the main corridors of the repository and that leads to the storage rooms. |

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| Brazil test | A method for the determination of the tensile strength of rock, concrete, ceramic, or other material by applying a compressive load radially to the outer surface of a test cylinder or disk. The cylinder or disk is supported on the opposite side by a tangent plane. |
| breakout | (1) See "demonstration breakout room." (2) The process of pulling up drill pipes or casings from a borehole and disconnecting them for stacking. |
| breccia | Rock consisting of sharp, angular fragments cemented together or embedded in a fine-grained matrix. |
| bridge plug | A downhole tool composed primarily of slips, plug mandrell, and rubber sealing elements that is run in and set in dense, nonfractured rock in a borehole to permanently isolate a zone. Multiple bridge plugs may be set in a borehole to isolate numerous zones. |
| brittle-ductile | See "ductile-brittle transition zone." |
| broadband sound | Sound that encompasses the audible frequencies. |
| Brunauer-Emmett-Tesler (BET) surface area | The total surface area of a powder or of a porous solid measured by the volume of gas (usually $N_2$) adsorbed on the surface of a known weight of the sample. |
| bulk air permeability | The ease with which air moves through a medium due to the total pressure difference. |
| bulk aquifer properties | The properties of an aquifer representing the combined effect of all individual values or variations within that aquifer, including fracture and matrix properties. |
| bulk density | The mass of an object or material divided by its volume, including the volume of its pore spaces. |
| bulk modulus | A modulus of elasticity relating a change in volume to the hydrostatic state of stress. It is the reciprocal of compressibility. |
| bulk permeability | Volume-averaged permeability. See "permeability." |
| bulk porosity | The total void volume divided by total volume of rock mass. |
| bulkhead | A tight partition of masonry, steel, or concrete used in the underground facility to control ventilation and to separate construction activities from waste emplacement activities. |

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| burnup | A measure of nuclear-reactor fuel consumption expressed either as the percentage of fuel atoms that have undergone fission or as the amount of energy produced per unit weight of fuel. |
| by-product material | Any radioactive material (except special nuclear material) yielded in or made radioactive by exposure to the radiation incident to the process of producing or utilizing special nuclear material. |
| cage | The platform of a mine hoist used to carry men or materials. |
| calc-alkalic series | An igneous rock or group of igneous rocks, in which the weight percentage of silica is between 56 and 61 when the weight percentages of CaO and $K_2O$+$NA_2O$ are equal. |
| calcic horizon | A diagnostic subsurface soil horizon, at least 15 cm thick, characterized by enrichment in secondary carbonates. |
| calcite and opaline silica deposits | See "calcite silica deposits." |
| calcite silica deposits | Deposits in the area of Yucca Mountain located at the surface and in fault zones consisting of calcite and opaline silica. |
| calcrete | A conglomerate consisting of surficial sand and gravel cemented into a hard mass by calcium carbonate, which precipitates from solution from infiltrating waters, or by calcium carbonate, which is deposited by the escape of carbon dioxide from vadose water. |
| caldera | A volcanic collapse structure, generally on the order of tens of kilometers in diameter, formed during the eruption of volumetrically large (tens to hundreds of cubic kilometers of dense rock equivalent) ash-flow and ash-fall tuff deposits. |
| calibration (of a model) | A part of the model validation process involving the trial-and-error adjustment of model parameters. |
| caliche | Gravel, sand, or desert debris cemented by porous calcium carbonate; also the calcium carbonate cement. |
| caliper log | A well log that shows the variation of diameter of an uncased borehole with depth. |
| calomel | A weathering product, $Hg_2Cl_2$, of cinnabar, HgS. |

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| candidate site | An area within a geohydrologic setting that is recommended for site characterization by the Secretary of Energy under Section 112 of the Nuclear Waste Policy Act of 1982, approved for characterization by the President under Section 112, or undergoing site characterization under Section 113. |
| canister | As used in this document, a canister is the initial metal receptacle in which solid radioactive waste is placed for transport to the repository. The canister is not intended to meet the 300- to 1000-year containment requirement of 10 CFR 60.113 (a)(1)(ii)(A) (see "container"). |
| capable fault | A fault that has exhibited one or more of the following characteristics, as described in 10 CFR Part 50: (a) movement at or near the ground surface at least once within the past 35,000 year or movement of a recurring nature within the past 500,000 year, (b) macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault, or (c) a structural relationship to a capable fault according to characteristics (a) and (b) such that movement on one could be reasonably expected to be accompanied by movement on the other. |
| capillary barrier | An interface between two geologic media that impedes unsaturated water flow because the media have different hydrologic properties. For example, flow from a medium with small pores or interstices into a medium with larger pores is inhibited if the receiving medium is unsaturated. |
| capillary forces (pressure) | A difference in pressure across the interface between two immiscible fluid phases jointly occupying the interstices of a rock. It is due to the tension of the interfacial surface, and its value depends on the curvature of that surface. |
| capillary fringe | The zone immediately above the water table in which all of the rock pores are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table. |
| carbon-14 dating | See "radiocarbon dating." |
| casing | (1) A liner in a shaft or borehole to prevent entry of loose rock, gas, or liquid, or to prevent the loss of circulating liquid into porous, cavernous, or fractured ground. (2) The process of inserting casing into a borehole (see "emplacement borehole liner" and "cladding hulls"). |

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| casing collar locator (CCL) | A well log used in conjunction with other logs, in cased holes, for depth control. The CCL responds to the thickness of ferrous metal at the threaded junctions between consecutive lengths of casing. |
| cask | A receptacle that holds one or more fuel assemblies, canisters, or disposal containers and provides shielding for highly radioactive materials during transportation. See "transporter cask," "shipping cask," and "transfer cask." |
| catchment area | (1) As applied to an aquifer, the recharge area and all areas that contribute water to it. (2) As applied to surface hydrologic systems, see "drainage basin." |
| cation exchange capacity (CEC) | A measure of the quantity of readily exchangeable cations neutralizing negative charge, expressed in moles of charge per unit mass. |
| cation-ratio dating | An experimental method for dating rock (desert) varnish. Curves (regression lines) representing the differential leaching rates of several minor elements in rock varnish (K+Ca:Ti) are calibrated using isotopically dated deposits to produce an area-specific plot of cation leaching ratios versus time. Using these calibrated cation-leaching curves, the time of initial varnish formation (minimum time since surface stabilization) can be dated for a variety of stable surfaces within the region. |
| Cauchy boundary condition | A semipervious boundary in flow through porous media media occurring when a thin layer of reduced permeability is formed at the ground surface. |
| cauldron | A caldera that has been eroded below the level at which the original topography is no longer recognizable. The location is inferred on the basis of the geometry of the erupted rock units and by the structural modification of the precaldera rocks. |
| characterization parameter | A physical property or condition (either measurable or calculable) whose value is to be determined in the site program in order to obtain, compute, or evaluate a performance parameter for a design or performance issue. |
| charophytes | One of a group of green algae in the order Charales and comprising the stoneworts. |
| chelation | Decomposition or disintegration of rocks or minerals resulting from the action of organisms or organic substances. |

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| chemisorption | A process in which a layer of atoms or molecules of one substance forms on the surface of a solid or liquid. The adsorbed layer is held by chemical bonds. |
| chromatographic | Of or relating to several techniques such that a distribution of a solute between a stationary phase and a mobile phase occurs. The stationary phase may be a solid or a liquid supported as a thin film on the surface of an inert solid. The mobile phase flowing over the surface of the stationary phase may be a gas or liquid. Types of chromatographic separations include adsorption, ion exchange, or partition (separation based on solubility) chromatography. |
| chronic intake | A continuous inhalation or ingestion exposure lasting for days or years. |
| cistern | An artificial reservoir for storing liquids, especially water. |
| cladding | The metallic outer sheath of a fuel element, generally made of stainless steel or a zirconium alloy. |
| cladding hulls | The empty metal tubes that remain after spent fuel is removed from them for reprocessing. |
| closed basin | A district draining to some depression or lake within its area, from which water escapes only by evaporation. |
| closed-system method | See "uranium-trend method." |
| closure | Final backfilling of the remaining open operational areas of the underground facility and boreholes after the termination of waste emplacement, culminating in the sealing of shafts. |
| cluster analysis | A procedure for arranging a number of objects in homogeneous subgroups based on their mutual similarities and hierarchical relationships. |
| cold trap | A tube whose walls are cooled with liquid nitrogen or some other liquid to condense vapors passing through it. |
| cold working | The increased resistance to further plastic deformation. Occurs when a metal or alloy is plastically deformed at temperatures below the recrystallization temperature of the alloy. |

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| collar | (1) The top or uppermost portion of a shaft. A concrete ring or slab around a shaft used to prevent water inflow and to support the headframe. (2) The threaded connector between consecutive lengths of casing. |
| colloform structures | Said of the rounded, finely banded kidney-like mineral texture formed by ultra-fine-grained rhythmic precipitation. |
| comb structures | A vein filling in which subparallel crystals, often of quartz, have grown perpendicular to the vein walls and thus resemble the teeth of a comb. |
| commercial waste | High-level radioactive waste generated in private industrial and other nongovernment facilities. |
| competent (geologic) | (1) A bed or stratum that is able to withstand the pressure of folding without flowage or change in original thickness. Competent strata tend to form parallel folds. (2) A bed or stratum that is resistant to weathering. |
| complementary cumulative distribution function (CCDF) | The CCDF is equivalent to one minus the cumulative distribution function. |
| complex response | Reaction of a fluvial system to a disruption of the equilibrium of the system. |
| complexing agent | A ligand (molecule or ion) that can donate one or more electron pairs to a metal atom or ion such that a complex is formed. |
| compliant-joint model | A conceptual and numerical model for a jointed medium whereby the deformation of the joints is treated separately from, and additionally to, the deformation of the intact material between joints. The stress-strain behavior of the joints and the matrix are idealized from observations of rock-mass behavior. In general, this approach does not allow for coupling of normal and shear joint responses. The total response of a representative volume of jointed material is posed as a constitutive stress-strain relationship for an equivalent homogenous material. |
| composite head | The combined or average hydraulic pressure of more than one hydrologic unit measured as a whole within a borehole. |
| compressibility | The change of specific volume and density under hydrostatic pressure; reciprocal of bulk modulus. |

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| compression index | The value of the slope of the line when the void ratio is plotted against the logarithm of the effective stress of a porous medium. |
| compressional wave | An elastic body wave for which particle motion is in the same direction as propagation for an elastically isotropic medium. In an anisotropic medium, the particle motion may deviate from the propagation direction. It is the fastest type of seismic wave and travels at about 6.0 to 7.7 km/s in the crust. |
| compressive strength | The maximum compressive stress that can be applied to a material, under given conditions, before failure occurs. |
| computed impedance tomography (CIT) | Tomographic imaging technique based on back projection along equal potential surfaces. |
| conceptual design | This design phase will concentrate on the surface and underground system, structure, emplacement, and component designs that require site characterization data and will provide the information to ensure that data-gathering plans relative to design will be adequately included in the Site Characterization Plan (SCP). Known site-specific data will be incorporated to assist in the identification of additional data needs, and sufficient design detail will be developed to ensure that all site data needs are identified. Data-accuracy requirements will be established and site-specific licensing issues related to site characterization will be identified. |
| conceptual perimeter drift boundary | The projection to the surface of the perimeter drift as defined in the conceptual design perimeter presented in Chapter 6 of the Site Characterization Plan. Perimeter drift "defines the outer limits of mined openings at waste emplacement depths" Rautman et al. (1987). |
| concordant | (1) A contact between an igneous intrusion and the country rock, which parallels the foliation or bedding of the latter. (2) Structurally conformable strata displaying parallelism of bedding or structure. (3) Radiometric ages determined by more than one method or by the same method from more than one mineral and that are in agreement. |
| conductivity | See "hydraulic conductivity" or "thermal conductivity." |
| conduits (hydrology) | A subterranean passage completely filled with water and always under hydrostatic pressure. |

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| confined aquifer | An underground water-bearing unit or formation with defined, relatively impermeable upper and lower boundaries. It contains confined ground water such that, if penetrated by a well, the water level will rise above the top of the aquifer. |
| confinement | As pertains to radioactivity, the retention of radioactive material within some specified bounds. Confinement differs from containment in that there is no absolute physical barrier in the former. |
| confining unit | A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers. |
| congruent leaching | A process of dissolving wherein the ratio of the rates of dissolution of constituents is proportional to their concentration ratios. |
| conjugate fault sets | A system of faults consisting of two sets symmetrically disposed about an inferred stress axis and of the same age and deformational episode. |
| connate water | Water no longer in circulation or contact with the present water cycle. Connate water is usually saline water trapped during the deposition of sediments and may be considered as "fossil water." |
| consolidation | The operation performed on spent fuel assemblies during which the upper and lower fuel-assembly tie plates are removed, the assembly spacer grids and any other assembly structural members are removed, and the fuel tubes are collected and formed into a closely packed bundle for insertion into a canister or container. The nonfuel structural members of the fuel assemblies are reduced in volume and placed in canisters or containers for shipment and disposal. |
| constant flux injection test | A type of hydraulic test, performed on a well, in which water is injected into an isolated interval of the well bore at constant flow rate. The method permits the evaluation of the hydraulic conductivity and storativity of a portion of the aquifer in the vicinity of the isolated interval. |
| constant head injection test | A test conducted to determine some hydraulic property, (i.e., hydraulic conductivity, transmissivity) in a well in which water is pumped in at a varied rate to keep the pressure or "head" constant. |
| constant-head node | A point within a numerical model at which the head is held constant. |

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| constitutive model | A mathematical model of a material or a process that expresses its essential quality or nature. A constitutive model is expressed by constitutive equations that mathematically express the relationship between the quantities of interest (e.g., constitutive equations establishing a linear elastic relationship between stress and strain). |
| constrained modulus | Ratio of axial stress to axial strain for a material tested triaxially with the minor and intermediate principal stress directions constrained. |
| contact (geology) | A plane or irregular surface between two different types or ages of rocks. |
| contact-handled transuranic waste | Transuranic (TRU) waste, usually contained in metal drums, whose surface radiation dose rate (less than or equal to 0.2 rem per hour) is sufficiently low to permit direct handling. Such waste does not usually require shielding other than that provided by its container. |
| contact-handled waste | Low-level radioactive waste that can be handled manually without exceeding established radiation exposure guidelines. |
| container | The metal barrier portion of the waste package that is placed around the waste form. |
| containment | The confinement of radioactive waste within a designated boundary. |
| containment barriers | Natural or man-made components of geologic disposal system designed to confine radioactive waste within a designated boundary. |
| containment period | The first several hundred years following permanent closure of a geologic repository when radiation and thermal levels are high, the uncertainties in assessing repository performance are large, and special emphasis is placed on the ability to contain wastes by waste packages within an engineered barrier system. |
| continental margin | The environment between the shoreline and the abyssal ocean floor including the continental shelf, continental borderland, continental slope and continental rise. |
| continuous-mining machine | A machine equipped with a rotating cutting head with pick-like bits for cutting into rock and for dropping the cuttings into a collection device for loading into cars or conveyers. |

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| continuum theory | In dealing with flow through porous media, the microscopic flow through the complex network of interconnected pores is disregarded in favor of the macroscopic overall average flow that takes place. |
| contoured stereonet | Stereonet plots containing multiple measurements from a geologic structure often reveal irregularities and the plot results in a scatter. Lines connecting areas of equal density (number of points per 1 percent area) are constructed to treat the data statistically. |
| control point | Any situation in a horizontal or vertical control system identified on a photograph and used as a base for a dependent survey. |
| controlled area | (1) A surface location, to be identified by passive institutional controls, that encompasses no more than 100 square kilometers and extends horizontally no more than five kilometers in any direction from the outer boundary of the original location of the radioactive wastes in a disposal system, and (2) the subsurface underlying such a surface location. |
| convection | A process of mass movement of portions of any fluid medium (liquid or gas) as a consequence of different temperatures in the medium and hence different densities. The process thus moves both the medium and the heat, and the term convection is used to signify either or both. |
| convective dispersion | Thermally induced dispersion of a liquid or a gas. |
| conventional light scattering (nephelometry) | The measurement of the cloudiness of a medium; especially the determination of the concentration or particle sizes of a suspension by measuring, at more than one angle, the scattering of light transmitted or reflected by the medium. |
| conventional shaft-sinking methods | Methods employing drilling, blasting, and mucking procedures in shaft construction. |
| convergence anchors | Fixtures set in rock serving as permanent reference points so that displacement between fixtures can be measured over time. |
| convergent boundary | A band along which moving plates collide and volume is lost either by shortening and crustal thickening or subduction and destruction of crust. The site of volcanism, earthquakes, trenches, and mountain building. |
| convergent flow | The coalescence of many overland flows downslope to make one large flow. |

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| cooling (spent fuel) | Storage of fuel elements after discharge from reactors, usually under water, to allow for the decay of short-lived radionuclides and hence the decrease of radioactivity and heat emission to acceptable levels. Synonymous with aging. |
| cordillera | A group of mountain ranges including valleys, plains, rivers, lakes, etc. Its component ranges may have various trends, but the cordillera generally will have one general direction. |
| corebarrel | Device used to remove drilled core from a borehole. |
| corehead | A hollow, cylindrical drill bit for carving, removing, and holding a core or sample of rock or soil material from the drill hole. |
| coring shovel | See "corebarrel." |
| cosmic-ray secondaries (secondary cosmic rays) | Radiation produced when primary cosmic rays enter the atmosphere and collide with atomic nuclei and electrons. |
| covariance | The arithmetic mean of the products of the deviations of corresponding values of two quantitative variables from their respective means. |
| credible abnormal conditions | The state of conditions expected to have a reasonable potential for occurring infrequently during the life of a repository. It is generally used to identify those conditions that need to be considered for use in developing contingency plans for related operations. |
| credible accident scenario | An accident scenario having a probability of occurrence of greater than a specified number to be determined. |
| credible scenario | A scenario having a probability of occurrence greater than or equal to $10^{-8}$ per year. |
| creep | Slow deformation that results from a long application of a constant stress. |
| crest-stage gauge | A gauge that records the highest level of a stream during a runoff event. A variety of different types of gauges do this, usually using floats to indicate the high-water mark. |
| critical path | Environmental exposure pathway that dominates the transport of material from the source of emission to human receptors. |

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| critical saturation | In an unsaturated environment, the saturation level that marks the transition between matrix-dominated fluid flow and fracture-dominated fluid flow. |
| critical threshold | The limits of equilibrium of a system, which, when exceeded, results in a change in the system or the system's responses. Examples include (1) sediment movement in streams, which begins at a critical threshold velocity, and (2) slope failure, which occurs when a critical threshold of slope stability is exceeded. |
| criticality | The condition in which a nuclear chain reaction is self-supporting. It occurs when the number of neutrons present in one generation cycle equals the number generated by the previous cycle. |
| crosshole geophysical method | See "borehole-to-borehole geophysical method." |
| crosshole recirculation test | A type of well test, usually involving a chemical tracer (or sometimes conducted only with water) in which water is injected into one well, either at constant flow rate or, less frequently, at constant pressure, and withdrawn from a nearby second well, to be reinjected into the first well. Once steady flow is established, a chemical tracer may be injected, the concentration of which is recorded as a function of time in the recirculation loop. The test yields information on the hydraulic and dispersive properties of the aquifer. |
| crustifications | Those deposits of minerals that are in layers and form crusts that have been distinctively deposited from solution. |
| cryosphere | That portion of the earth's surface that is permanently frozen. |
| cumulative distribution function (CDF) | For a given value of $\zeta$ and a random variable R, the CDF of R at $\zeta$ is the function that gives the probability that R is less than or equal to $\zeta$, written $P(R \leq \zeta)$. That is, the CDF accumulates probabilities of all values of R less than or equal to $\zeta$. |
| cumulative impact | Projected impact of a proposed facility in combination with other existing and proposed facilities and actions. |
| cumulative releases of radionuclides | The total number of curies of radionuclides entering the accessible environment in a 10,000-year period. |

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| Curie point | The temperature above which thermal agitation prevents spontaneous magnetic ordering. Specifically, the temperature at which the phenomenon of ferromagnetism disappears and the substance becomes simply paramagnetic. |
| cyclic deformation | Subjecting a sample to multiple loading cycles such that the peak load is never surpassed. |
| damaged zone | See "modified permeability zone." |
| damping factor | The ratio of the observed damping to that required for critical damping (the point at which the displaced mass returns to its original position without oscillation). |
| datum (in geology) | The top or bottom of a bed of rock, or any other surface, on which contours are drawn (e.g., a datum horizon). |
| daughter products | A nuclide that results from radioactive decay. For example, radium-226 decays to radon-222, which, in turn, decays to polonium-218. Thus, radon is the daughter of the radium, and the polonium is the daughter of the radon. |
| debris (geomorphology) | Any surficial accumulation of loose material detached from rock masses by decay and disintegration; it mainly consists of rock fragments and soil. |
| debris cone | An alluvial fan with steep slopes and composed of coarse fragments. |
| decay (radioactive) | (1) The process whereby radioactive materials undergo a change from one nuclide, element, or state to another, releasing radiation in the process. This action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide. |
| decay chain | The sequence of radioactive disintegrations in succession from one nuclide to another until a stable daughter product is reached. |
| decay coefficient | A constant, characteristic of a nuclear species, which expresses the probability that an atom of the species will decay in a given time-interval. For a large number of atoms of a species, the decay constant is the ratio between the number of decaying atoms per unit of time and the existing number of atoms. |

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| decollement | Detachment structure of strata due to deformation, resulting in independent styles of deformation in the rocks above and below. A decollement is associated with folding and overthrusting. |
| decommissioning | The permanent removal from service of surface facilities and components necessary for preclosure operations only, after repository closure, in accordance with regulatory requirements and environmental policies. |
| decontamination | The removal of unwanted material (especially radioactive material) from the surface of or from within another material. |
| deconvolution technique | A linear mathematical operation whereby the effects of convolution on a signal are reversed to recover the signal. Convolution has many analogs in nature, such as multiple additive reflections of a seismic signal from different reflecting horizons in a layered sequence of geologic strata. |
| decoupling | The act of disconnecting differing mechanical stress regimes by an interfering boundary such as a fault or fault zone. |
| decrepitation | The shattering of a rock mass or rock sample caused by the buildup of excessive pressures in contained fluids as a result of heating, or the action of differential thermal expansion or contraction of its heated grains. |
| defense high-level waste | High-level radioactive waste generated by activities related to the national defense program, including the manufacture of nuclear weapons, the operation of naval reactors, and research and development at weapons laboratories. |
| deflectometer | A displacement-measuring instrument that is installed in a drillhole or embedded in a structure such as a dam. The deflectometer detects relative displacement of different points along the drillhole, in the plane perpendicular to the hole axis. The instrument may consist of an assembly that is permanently installed, or a sonde that is deployed within special tubing or casing. |
| deformation modulus | See "modulus of deformation." |
| degradation | The general lowering of the surface of the land by erosive processes, especially by the removal of material by flowing water. |

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| delta function | A mathematical function that is infinite when its argument is zero, and zero elsewhere, and has the property that its integral over any interval that includes zero is unity. |
| demonstration breakout room (DBR) | A horizontal drift, located in an exploratory shaft, which will accommodate a number of rock mechanics tests to be performed during exploratory shaft facility (ESF) construction. |
| dense rock equivalent (DRE) | A measure of volume used when describing tuff deposits. DRE is the equivalent volume of a tuff deposit when it is compressed to the density of hard rock of equivalent composition. |
| density borehole compensated (DBC) log | The record resulting from use of formation density logging tool with multiple detectors, which allows an adjustment to the density value for each depth point to compensate for borehole rugosity at or near that point. (See "formation density log with dual proximity" and "multidetector compensated gamma-gamma tool.") |
| desert pavement | A residual concentration of wind-polished, gravel-sized rock fragments, mantling a desert surface where wind has removed most of the smaller particles, and the lag surface protects the underlying material from further eolian erosion. |
| desert varnish | A thin, dark, shiny film or coating, composed of hydrated manganese and iron oxides with trace silica, formed on the surfaces of rock fragments, as well as on ledges and rock outcrops in desert regions. It is believed to be caused by exudation of mineralized solutions from within and deposited by evaporation on the surface. |
| design bases | The principal determinants that establish the overall repository design. There are two bases for the repository design: (1) the waste to be disposed and (2) the geologic characteristics of the site. |
| design-basis event | A credible accident or natural phenomenon (e.g., earthquakes or floods) that is used to establish design bases because its consequences are the most severe of all those postulated for other credible accidents or phenomena. |
| design earthquake | A hypothetical earthquake against which protective measures are taken. |

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| design life | The period of time for which a structure, system, or component is designed to perform its intended function. The repository design life ends when the repository is of no further operational use, waste retrieval is no longer a concern, and closure and decommissioning begin. |
| design package | Consists of the design of the repository (design drawings), supporting analysis, operating plan, and equipment demonstrations. |
| desorption | Freeing from a sorbed state. Removing a sorbed substance by the reverse of adsorption or absorption. |
| determination | A decision by the Secretary of Energy that a site is suitable for site characterization for the selection of a repository site or that a site is suitable for the development of a repository, consistent with applications of the guidelines of Subparts C and D in accordance with provisions set forth in Subpart B of 10 CFR Part 960. |
| development area | The underground area being prepared for emplacement of waste packages. Development includes excavation of the emplacement drifts and boreholes, installation of rock support in the drifts, and outfitting the emplacement boreholes with liners and covers. As the panel from the development of a panel is completed, bulkheads are installed to seal the panel from the development area and the panel is added to the ventilation circuit for the waste emplacement area. |
| deviatometer | A geophysical instrument that is lowered into a well to measure the deviation of the well from a vertical line originating at the bottom of the well. Most deviatometers use the earth's magnetic field for positional reference, although some are gyroscopic in nature. |
| deviatoric stress | In the engineering discipline of rock mechanics, the difference between the major principal stress and the minor principal stress. |
| dielectric constant | The force F between two electric charges e, separated by a distance r in a vacuum, is given by $F = e^2/r^2$. In any other medium this relationship becomes $F = e^2/Dr^2$ where D is the dielectric constant of the medium. The dielectric constant is a measure of the polarity of the medium. |
| differential extension | A situation in which the offset or separation along the strike of a fault or fracture increases in one direction from an initial point and decreases in the other direction. |

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| differential thermal analysis (DTA) | Thermal analysis carried out by uniformly heating or cooling a sample that undergoes chemical or physical changes, while simultaneously heating or cooling in identical fashion a reference material that undergoes no changes. |
| diffusion | If the concentration at one surface of a layer of a liquid is $d_1$ and at the other surface, $d_2$, the thickness of the layer h and the area under consideration A, then the mass of the substance that diffuses through the cross-section A in time t is $$m = \frac{\Delta A\ (d_2 - d_1)t}{h}$$ where $\Delta$ is the coefficient of diffusion. |
| diffusivity | Diffusivity or coefficient of diffusion is the amount passing through an area in a given direction in a given amount of time. |
| dilatancy | An increase in the bulk volume during deformation caused by a change from close-packed structure to open-packed structure, accompanied by an increase in the pore volume. The latter is accompanied by rotation of grains, microfracturing, and grain boundary slippage. |
| dip slope | A slope of the land surface with a slope angle approximately equal to the dip of the underlying rocks. |
| direct tensile strength | A directional property of a material that is determined by measuring the tensile force required to induce failure. The force exerted on the sample must be purely tensile, if possible, and be neither compressive nor involve applied shear stress. |
| Dirichlet boundary condition | A boundary condition encountered in flow through porous media that occurs when the flow domain is adjacent to a body of open water. |
| discharge flux | The amount of flux discharging from a specified region. |

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| discordant | (1) A contact between an igneous intrusion and the country rock that is not parallel to the foliation or bedding of the latter. (2) Structurally unconformable. Said of strata lacking parallelism of bedding or structure. (3) Said of radiometric ages, determined by more than one method for the same sample or for coexisting minerals that are in disagreement beyond experimental error. (4) Said of topographic features that do not have the same or nearly the same elevation. |
| dispersivity | A characteristic property of a porous medium, which is one of two components of the coefficient of hydrodynamic dispersion. Also known as dynamic dispersion. |
| displacement | A general term for the relative movement of the opposing sides of a fault. |
| disposal | The emplacement in a repository of high-level radioactive waste, spent nuclear fuel, or other highly radioactive material with no foreseeable intent of recovery, whether or not such emplacement permits the recovery of such waste and the isolation of such waste from the accessible environment. |
| disposal container | See "container." |
| disposal system | See "mined geologic disposal system." |
| disqualifying condition | A condition that, if present at a site, would eliminate that site from further consideration. |
| disruptive event | A natural or human-induced event that would change the geohydrologic, geochemical, or rock characteristics of the site from their present conditions or adversely affect the expected performance of the engineered barrier system. |
| disruptive scenarios | See "disruptive event." |
| dissemination | Said of a mineral constituent of a rock deposit in which the desired minerals occur as scattered particles in the rock. |
| dissolution kinetic parameters | Those physical and chemical conditions that influence the rate at which a mineral will dissolve. |
| distribution coefficient ($K_d$) | The ratio of the activity on solid phase per unit mass of solid to the activity in solution per unit volume of solution under equilibrium conditions. This ratio not under equilibrium conditions is given by $R_d$. |

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| distribution function (statistical) | The distribution function F(x) (x is assumed to be continuous) is the probability of occurrence in the interval $(x, x + \Delta x)$ divided by $\Delta x$ as the interval size $(\Delta x)$ shrinks to zero. |
| disturbed conditions | Conditions arising from the occurrence of disruptive events. |
| disturbed zone | That portion of the controlled area, excluding shafts, whose physical or chemical properties are predicted to change as a result of underground facility construction or heat generated by the emplaced radioactive waste such that the resultant change of properties could have a significant effect on the performance of the repository. |
| divergent zone | See "accretionary boundary." |
| dolly | A device that cradles the waste container within the horizontal emplacement borehole. The dolly is emplaced in the borehole along with the container it carries. |
| domino model | See "planar-rotational faults." |
| dose | The quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. |
| dose commitment | The integrated dose that results from an intake of radioactive material when the dose is evaluated from the beginning of the intake to a later time; also used for the long-term integrated dose to which people are considered committed because radioactive material has been released to the environment. |
| dose equivalent (radiation) | An estimate of the amount of biological damage done by the deposition in tissue of a given unit of absorbed radiation dose. The dose equivalent is obtained by multiplying the absorbed radiation dose by a quality factor. The unit of dose equivalent is the rem. |
| dose limit | The limit established by the U.S. Environmental Protection Agency or the U.S. Nuclear Regulatory Commission for the exposure of people to radiation. |
| double-couple focal mechanism | Simplist mechanism causing displacement along a fault and conserving angular momentum such that the net torque is zero. |
| double-ring infiltrometer | A device used to measure infiltration. Consists of two concentric rings placed around a testing area. |

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| down-dip | A direction that is downward from and parallel to the dip of a structure or surface. |
| downwasting | The general term for the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stress. |
| drag fold | A minor fold, usually one of a series, formed in an incompetent bed lying between more competent beds, produced by movement of the competent beds in opposite directions relative to one another. |
| drainage basin | A region or area bounded by a divide and occupied by a drainage system; specifically, the tract of country that contributes water to a particular stream channel or system of channels, a lake, reservoir, or other body of water. |
| drainage capture | See "stream capture." |
| drawdown | The lowering of the water table or potentiometric surface caused by pumping. |
| drift | Horizontal, or nearly horizontal, mined passageway. (See "main," "emplacement drift," and "perimeter drift.") |
| drift-pumpback test | A type of well test involving a single well and a chemical tracer in which the tracer is injected into an isolated interval of the well, allowed to drift with the natural motion of the ground water; then pumped back out. The temporal variation of the returning tracer's concentration provides information on the dispersive and transport properties of the aquifer. |
| drill-and-blast mining | A method of mining in which holes are drilled into the rock and then loaded with explosives. The blast from the explosives breaks the rock so that the rock can be removed. The underground opening is expanded by repeated drilling and blasting. |
| drill and test | Hydrologic testing of selected rock intervals when each interval is first penetrated by a borehole. This testing takes place before a borehole is completed to its total depth. |
| drill cutting (well cuttings) | Rock chips cut by a bit in the process of well drilling and removed from the hole in the drilling fluid in rotary drilling, in the bailer in cable-tool drilling, or by air when air is the drilling fluid. |

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| drilling fluid | The circulation medium used in drilling to remove cuttings from the bit, to carry cuttings to the surface for disposal, to cool the bit, to stabilize the borewall in open intervals (as with drilling mud), and to energize downhole drilling tools (as with mud meters or air hammers). |
| drillstring | (1) A term used in rotary drilling for the assemblage in a borehole of drill pipe, drill collars, drill bit, and core barrel (if in use), connected to and rotated by the drilling rig at the surface. (2) A term used in cable drilling for the assemblage in a borehole of drill bit, drill stem, cable, and other tools, connected to the walking beam at the surface. |
| drive core | A core sample acquired by special tools that force a sampling cup or tube into the borewall. This method works best in soft rock formations. |
| Drucker-Prager yield criterion | This criterion is used to evaluate the yield response of a material subjected to a three-dimensional stress field. It states that the material will yield in a ductile fashion if the combination of stresses, as computed by an equation defining the criterion, exceeds the experimentally determined limiting values of the criterion for that material. |
| drusy cavities | An irregular cavity or opening in a vein or rock, having its interior surface or walls lined (encrusted) with small projecting crystals, usually of the same minerals as those of the enclosing rock, and sometimes filled with water. |
| dry-bulb (DB) temperature | Temperature that is indicated by a conventional dry thermometer and is not dependent on atmospheric humidity. |
| dual induction focused log (DIFL) | A geophysical logging tool for measurement of the formation resistivity, which uses several coils to focus the signal, enhancing the true formation response at the expense of the material nearest the borehole, and improving vertical (axial) resolution. |
| ductile-brittle transition zone | The hypothesized zone of decoupling at the transition between brittle and ductile behavior that occurs at a depth of approximately 15 km in the Great Basin. Below this zone, extension probably occurs by ductile stretching, thinning, or intrusions of basaltic material from below or by a combination of these factors. Earthquakes generally do not occur below the transition zone. |

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| ductile fold | A fold that undergoes plastic deformation rather than brittle deformation. The beds, especially the competent beds, tend to be the same thickness regardless of their position on the fold. The incompetent beds may thin at the limbs and thicken at the hinges. |
| durations (coda) | The latter part of a seismogram following the early, identifiable surface waves and in which arrive long trains of waves. It may last for hours, especially if long oceanic paths are involved. |
| duripan | A diagnostic subsurface soil horizon that is characterized by cementation by silica and by accessory cements. Duripans occur mainly in areas of volcanism that have arid or Mediterranean climates. |
| dust devils | A small but vigorous whirl-wind, usually of short duration, rendered visible by dust, sand, and debris picked up from the ground. |
| dynamical models (statistical) | A model is said to be dynamic if it possesses either or both of these properties: (1) at least one variable occurs in the governing equations with value taken at different points in time or in the form of time-derivatives, etc., (2) at least one equation contains a function of time. |
| earth flow | A slow flow of unconsolidated earth material lubricated with water, occurring as either a low-angle terrace flow or a somewhat steeper but slow hillside flow. |
| earthquake focal mechanisms | All processes that take place at the focus of an earthquake. All kinds of faulting (thrust, normal, strike-slip) give rise to different, yet common forms of energy release. If the earthquakes generating these faults are considered as point sources, the "focal mechanism" can be analyzed by looking at the radiation pattern (zones of dilatation and compression). |
| eddy-correlation technique | A method of studying the effects of sea surface on the air above it by measuring simultaneous fluctuations of the horizontal and vertical components of the airflow from the mean. |
| effective bulk permeability | The permeability of a portion of rock mass sufficiently large to include the effects of cracks, joints, faults, etc., as well as the effects of interconnected pores. See also "permeability." |

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| effective neutron multiplication factor, $K_{eff}$ | The ratio of the number of neutrons in a given generation to the number of neutrons in the immediately preceding generation. For criticality, $K_{eff}$ must be unity (if $K_{eff} > 1$ then supercritical). |
| effective permeability | The measure of the ease with which a particular fluid can move through a porous medium. For example, soils have differing effective permeabilities for water and air. |
| effective porosity | The amount of interconnected pore space and fracture openings available for transmission of fluids, expressed as the ratio of the volume of the interconnected pores and fracture openings to the volume of rock. |
| effective precipitation | That part of precipitation producing runoff. |
| effective saturated thickness | That thickness of an aquifer contributing to the flow of ground water. |
| elastic compression | Compression in which the strain is reversible and the body recovers its original shape when the stresses are removed. |
| elastic modulus (modulus of elasticity) | The ratio of stress to its corresponding strain under given conditions of load, for materials that deform elastically. |
| elastic-plastic media | A material in which instantaneous elastic strain at a constant stress is followed by continuously developed permanent strain as long as the stress is maintained. |
| elastoplastic strain hardening | Material behavior in which the rate of development of permanent, plastic strain in an elastic-plastic material subjected to constant stress diminishes as the total amount of such plastic strain accumulates. |
| electric log (E-log) | The generic term for a well log that displays electrical measurements of induced current flow (e.g., resistivity log, potential curve log) in the rocks of an uncased borehole. |
| electrical conductivity | A measure of the ease with which a conduction current can be caused to flow through a material under the influence of an applied electric field. Electrical conductivity is the reciprocal of resistivity. |
| electrical resistivity | The electrical resistance per unit length of a unit cross-sectional area of a material. |

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| electrical survey (ES) | A generic term referring to the combined use of several geophysical logging tools: self potential (SP), resistivity in short and long normal configuration, and resistivity in a lateral configuration. These logs are sensitive to the following properties of the geologic section penetrated by a drillhole: resistivity of the rock matrix, porosity, electrical properties of the formation fluid, electrical properties of the drilling and or other fluid in the well base, electrical anisotropy, and inhomogeneity of the rock and the temperature downhole. |
| electrochemical potentiokinetic reactivation (EPR) | Electrical force generated by means of chemical action in manufactured cells (dry batteries) or by natural means (galvanic reaction). |
| electron microprobe | An analytical instrument that uses a finely focused beam of electrons to excite x-ray emission from selected portions of a sample. From the emitted x-ray spectrum the composition of the sample at the point of excitation can be determined. |
| electron spin resonance | Resonance occurring when electrons undergoing transitions between energy levels in a substance are irradiated with electromagnetic energy of a proper frequency to produce maximum absorption. |
| electrostatic adsorption | The removal of a solute particle from a solution as a result of an electrostatic charge disparity between the particle and the rock matrix. A particle with a strong charge disparity may displace one with a weaker disparity on the rock matrix in a process known as ion exchange. |
| elute | To remove adsorbed material from an adsorbent by means of a solvent. |
| emplacement | The act of placing waste containers in prepared positions. For the proposed repository at Yucca Mountain, two methods are currently being considered: emplacement of a single waste container in a shallow vertical borehole in the floor of the emplacement drift or emplacement of multiple waste containers in long horizontal boreholes in the wall of the drift. |
| emplacement borehole | A borehole used specifically for emplacement of waste. |

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| emplacement borehole liner | A sleeve placed in a vertical or horizontal borehole to prevent sloughed rock from interfering with the emplacement or removal of waste packages. It does not serve a shielding or containment function. The liner runs the complete length of horizontal boreholes, but, in vertical boreholes, extends only from the mouth of the borehole to just below the shoulder of the emplaced waste container. See "casing." |
| emplacement drift | A drift in which waste emplacement boreholes are located. |
| emplacement envelope | The components that surround the emplaced waste containers(s). The emplacement envelope includes boreholes, liner(s), borehole shield plug, and borehole cover. |
| emplacement horizon | The specific geologic stratum or portion thereof in which waste will be emplaced below the earth's surface. A portion of the Topopah Spring Member of the Paintbrush Tuff is currently the target emplacement horizon at Yucca Mountain. |
| en echelon | Geologic features that are in an overlapping or staggered arrangement (e.g., faults). Each is relatively short, but collectively they form a linear zone in which the strike of the individual features is oblique to that of the zone as a whole. |
| engineered barrier system (EBS) | (1) The waste packages and the underground facility (10 CFR Part 60); (2) The man-made components of a disposal system designed to prevent the release of radionuclides from the underground facility or into the geohydrologic setting. The EBS includes the radioactive-waste form, radioactive-waste canisters, materials placed over and around such canisters, any other components of the waste package, and barriers used to seal penetrations in and into the underground facility (10 CFR Part 960). |
| enrichment | The processes by which the relative amount of one constituent material or element contained in a rock is increased. This may be due either to the removal of other constituents selectively or to the introduction of increased amounts from an external source. |
| environmental assessment (EA) | The document required by Section 112(b)(1)(E) of the Nuclear Waste Policy Act of 1982. |
| environmental impact statement (EIS) | The document required by Section 114 of the Nuclear Waste Policy Act of 1982 as amended by the Nuclear Waste Policy Amendments Act of 1987. |

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| epeirogeny | Movements of uplift and subsidence that have produced the broader features of the continents and oceans, e.g., plateaus and basins, in contrast to orogeny, which has produced mountain chains. |
| ephemeral drainage | Drainage of a stream or portion of a stream that flows briefly in direct response to precipitation in the immediate vicinity and whose channel is at all times above the water table. |
| epicenter (earthquake) | The point on the earth's surface directly above the exact subsurface location of an earthquake. |
| epiclastic rock | A rock formed at the earth's surface by consolidation of fragments of preexisting rocks. A sedimentary rock whose fragments are derived by weathering or erosion. |
| epithermal | Said of a hydrothermal mineral deposit or alteration typically formed within about 1 kilometer of the earth's surface in a temperature range of 50 to 200°C. |
| epithermal neutron log | A well log of the wall-contact sonde type that measures epithermal neutron radiation in the 0.1 to 100 eV energy range, which is induced by bombardment with neutrons at several MeV energy. It is similar to the thermal neutron tool but relatively insensitive to the presence of thermal neutron absorbers such as chlorine, boron, or lithium. |
| epithermal neutron porosity | A porosity estimate determined from the epithermal neutron response. It is generally calculated using either (1) a calibration relationship developed using samples of the formation material, or (2) a standard calibration relationship that ensures full saturation with fresh water and a rock matrix of pure limestone. |
| equivalent continuum model | A conceptual and numerical model whereby the mechanical, thermomechanical, hydrologic, or geochemical response of a locally heterogeneous rock mass is characterized on a relatively large scale by the appropriate properties of a homogeneous continuum. |
| equivalent energy density concept | A procedure for determining the areal power density for wastes that differ in age and burnup from the average values used in determining the design basis areal power density. The equivalent areal power density is that waste loading that deposits the same energy in the host rock over a fixed period of time (usually 2,000 years) as would waste having the average characteristics. |

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| eugeosyncline | A geosyncline in which volcanism is associated with clastic sedimentation; the volcanic part of an orthogeosyncline that is located away from the craton. |
| Eulerian-Lagrangian solution technique | Technique for the solution of ground-water flow and transport. |
| Eureka low | A subprovince of the Great Basin with anomalously low heat flow in southern Nevada. |
| evaluation | The act of carefully examining the characteristics of a site in relation to the requirements of the qualifying and disqualifying conditions specified in the guidelines of 10 CFR 960 Subparts C and D. Evaluation includes the consideration of favorable and potentially adverse conditions. |
| evapotranspiration | A term embracing that portion of the precipitation returned to the air through direct evaporation or by transpiration of vegetation; no attempt is made to distinguish between the two. |
| EX-size borehole | A 38-mm (1.5-in.) diameter borehole. |
| exfoliation | The process by which concentric scales, plates, or shells of rock, from less than a centimeter to several meters in thickness, are successively spalled or stripped from the bare surface of a larger rock mass. |
| expected partial performance measure (EPPM) | A measure for determining whether a scenario class needs to be included in the final calculation of the complementary cumulative distribution function (CCDF). |
| expected repository performance | The manner in which the repository is predicted to function, considering those conditions, processes, and events that are likely to prevail or may occur during the time period of interest. |
| explicit-dynamical models | General circulation models in which day-to-day synoptic-scale weather systems and their associated patterns of precipitation are treated explicitly, requiring time steps of the order of minutes to hours for the atmospheric portion of the climate model. |
| exploratory shaft | A vertical shaft of sufficient depth to allow in situ characterization of the emplacement horizon. The shaft is large enough to allow people and test equipment to be transported from the surface to the underground excavations. |

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| exploratory shaft facility (ESF) | The exploratory shafts, any associated surface structures, and underground openings constructed for the purpose of site characterization. |
| exposure | The radiation dose received by the absorption of radiation or the intake of a radionuclide by any individual. |
| extensometer | A device used to measure deformation. |
| extraction ratio | The ratio of the excavated area of all drifts to the total area. (Note that in the case of horizontal emplacement orientation, the area of the emplacement boreholes is not included in the ratio.) |
| fabric | The spatial and geometrical configuration of all those components that make up a deformed rock, including texture, structure, and preferred crystallographic orientation. |
| faceted spur | A ridge, or a divide between stream valleys, that has an inverted-V face in cross section that is produced by faulting or erosion. |
| facility | Any structure, system, or system component, including engineered barriers, created by the U.S. Department of Energy to meet repository performance or functional objectives. |
| facility cask | See "transporter cask." |
| falling head injection test | A test to determine the hydraulic conductivity in which the hydraulic head is allowed to fall during a specified period of time. The hydraulic conductivity is calculated from the drop in hydraulic head and the cross-sectional area. |
| fallout | Fission and activation products, produced by the above-ground detonation of a nuclear device, that precipitate back down to the land surface. |
| fan | See "alluvial fan." |
| fanglomerate | A sedimentary rock consisting of slightly water-worn heterogeneous fragments of all sizes, deposited in an alluvial fan, and later cemented into a firm rock. |
| far field | That portion of the host rock surrounding the underground facility within which the thermal effects of the emplaced waste can be analyzed by considering only the areal power density without consideration of the specific geometric characteristics of the underground facility. |

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| fault | A fracture or zone of fractures along which there has been displacement of the side relative to one another, parallel to the fracture or zone of fractures. |
| fault trace (line) | The line of a fault plane on the ground surface or on a reference plane. |
| favorable condition | A condition that, though not necessary to qualify a site, is presumed, if present, to enhance confidence that the qualifying condition of a particular guideline can be met. |
| felsic | Amnemonic term derived from "Fe" for feldspar, "l" for feldspathoids, and "s" for silica and applied to light-colored rocks containing an abundance of one or all of these constituents. |
| ferricrete | A conglomerate consisting of surficial sand and gravel cemented into a hard mass by iron oxide derived from the oxidation of percolating solutions of iron salts. |
| ferriginous zone | Pertaining to or containing iron (e.g., a zone in a sandstone that is cemented with iron oxide). |
| Fickian dispersion | Dispersion that follows Fick's first law: The mass of diffusing substance passing through a given cross section per unit time is proportional to the concentration gradient. |
| field density test | See "rubber-balloon method." |
| final procurement and construction design | The design that will develop the final (working) drawings and specifications for procurement and construction. The completion of this design phase will match the completion of the Title II design effort for the entire repository. This design phase will emphasize the completion of design of ancillary support items, final design refinement for the items necessary to demonstrate compliance with the design criteria and performance objectives of 10 CFR Part 60, the development of construction bid packages for all systems, and the development of final procurement and construction schedules. |
| fines | Clay- and silt-sized soil particles with a maximum particle size less than 8 mm. |

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| first motion | The initial motion of the ground resulting from a seismic event. A first-motion study or fault-plane solution, is a technique by which motion on fault planes associated with earthquakes can be determined, thus giving information on the orientation of faults and slip directions of earthquakes. |
| first-order landscape element | The primary divisions of the earth's physiographic features, consisting of the continents and ocean basins. |
| first-year activities | Site characterization activities, as defined by the NWPA, that will be initiated during the first year of site characterization. |
| fission product | A nuclide produced by the fission of a heavier element. |
| fission track dating | A method of calculating an age in years by determining the ratio of the spontaneous fission-track density to induced fission tracks. The method which has been used for ages from 20 years to $1.4 \times 10^9$ years, works best for micas, tectites, and meteorites, and is also useful for determining the amount and distribution of the uranium in the sample. |
| fission tracks | The paths of radiation damage made by the spontaneous fission of uranium-238 impurities. |
| flatjack | A hollow metal cushion formed of two nearly flat plates, butt-welded around the edges, and inflated under controlled pressure to bear against restraints. A flatjack is used to test in situ stress and rock-mass deformability. |
| flocculate | The act or process by which a number of individual, minute, suspended particles are tightly held together in clot-like masses or are loosely aggregated or precipitated into small lumps, clusters, or granules. |
| flow breccia | A breccia that is formed contemporaneously with the movement of a lava flow; the cooling crust becomes fragmented while the flow is in motion and is either incorporated into the flow, or falls in front of the moving flow and is overridden. |
| flow path | The theoretical line that ground water follows in moving from a recharge area to a discharge area. |
| flow rocks | Igneous rocks that have been emplaced by the physical process of flowing. |

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| flow unit | A group of stacked pyroclastic deposits that were emplaced as separate ash-flow tuffs during the same or closely associated eruptive event(s). |
| fluid density log | A record in a wellbore of the variation of the density of a fluid column with depth. The record is most commonly made during the drilling process as a means of assessing the properties and performance of the drilling fluid. |
| fluid inclusion | A cavity, typically 1.0 to 100.0 microns in diameter, in a mineral containing liquid or gas, formed by the entrapment in crystal irregularities of fluid, commonly that from which the rock crystallized. |
| fluid potential | The mechanical energy per unit mass of a fluid, (e.g., water or oil), at any given point in space and time, with respect to an arbitrary state and datum. The fluid potential is the total head multiplied by the acceleration due to gravity. |
| fluid pressure (hydrostatic pressure) | The pressure exerted by water at any given point in a body of water at rest. The hydrostatic pressure of ground water is generally due to the weight of water at higher levels in the zone of saturation. |
| flume | An artificial, inclined channel used for conveying water. |
| fluorometry | Measurement of the intensity and color of fluorescent radiations. |
| flushing fluid (drill fluid) | Usually pure or mud-laden water (sometimes applied to compressed air, natural gas, or oil) circulated through a drill string to keep the bit cool and to wash away the cuttings produced by the bit face. Also called circulation fluid. |
| flux | The ratio of the volume of fluid per unit area per unit time. Also known as specific discharge. |
| fluxgate magnetometer | An electrical instrument that measures the change in magnetic field along the axis of its sensor with a sensitivity of one gamma or more. Used on the ground, it measures the relative vertical magnetic intensity. |
| fly ash | All particulate matter that is carried in a gas stream. |
| focal depth (depth of focus) | The distance from the focus of an earthquake to the epicenter. |

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| focal mechanism (fault-plane solution) | Determination of the orientation of a fault plane and the direction of slip motion on it from an analysis of the sense of the first motion of the P waves or the amplitudes of the P waves, S waves, and surface waves. |
| focal sphere | An arbitrary reference sphere drawn about the hypocenter or focus of an earthquake, to which body waves recorded at the earth's surface are projected for studies of earthquake mechanisms. |
| focus | The initial rupture point of an earthquake where strain energy is first converted to elastic wave energy. |
| foliation | A general term for a planar arrangement of textural or structural features in any type of rock. The planar structure that results from flattening of the constituent grains of a metamorphic rock. |
| forging | Using compressive force to shape metal by plastic deformation. |
| formation density log (FDL) | Vertical profile of changes in density of a formation around a borehole. The intensity of scattered gamma radiation induced by irradiating the formation with medium-energy gamma rays reflects the electron density of the formation, which is proportional to true blue density. This technique is mainly used as a porosity indicator. |
| formation density log (FDL) with dual proximity (FDD) | A formation density logging tool with two or more detectors at different distances from the gamma source to compensate for the effects of mud cake and possibly formation invasion, and to detect borehole rugosity effects. |
| formation water | Water present in a water-bearing formation under natural conditions, as opposed to introduced fluids such as drilling mud. |
| fractional crystallization | Crystallization of a magma body in which newly formed crystals are removed from communication with a melt before they can react with the residual liquid. |
| fracture | A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fractures include cracks, joints, and faults. |
| fracture aperture | The perpendicular distance separating the adjacent rock walls of an open discontinuity. |

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| fracture conductivity | The hydraulic conductivity within a fracture or system of fractures. |
| fracture contact area | The cumulative area of a rock fracture over which the mating walls of the fracture are actually in mechanical contact. Expressed as a proportion of the total fracture area. |
| fracture flow | The movement of water through a fracture system. |
| fracture permeability | Permeability as a result of fractures. Where fracture density is high, fracture permeability is high. |
| fracture persistence | The areal extent or size of a discontinuity within a plane. It can be crudely quantified by observing the discontinuity trace lengths on the surface of exposures. |
| fracture pore system | See "fractured porous media." |
| fracture porosity | The portion of large-scale rock-mass bulk porosity that is caused by voids associated with opening or aperture of fractures. |
| fractured porous media | Media exhibiting porosity resulting from the presence of joints or other fractures as well as from the rock medium itself. |
| free air | That portion of the earth's atmosphere, above the planetary boundary layer, in which the effect of the earth's surface friction on the air motion is negligible. |
| free energy | The maximum amount of work in addition to expansion work that can be obtained from a given process occurring at constant temperature and pressure. |
| free flow | In hydraulics, flow that is not disturbed by submergence or backwater. |
| free surface | The upper surface of a layer of fluid where the pressure on it is equal to the external atmospheric pressure. |
| free water | Water in the soil in excess of field capacity that is free to move in response to the pull of gravity. |

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| Freundlich isotherm | A mathematical model representing the partitioning of solutes between liquid and solid phases in a porous medium as determined by laboratory experiments. The Freundlich isotherm is commonly expressed in graphical form where mass sorbed per unit mass of dry solids is plotted against the concentration of the constituent in solution. |
| frit glass | (1) A glass containing fluxing material and employed as a constituent in a glaze body, or other ceramic composition. (2) A glassy material produced by fusing a mixture or enamel and quenching it in water. |
| fuel | As used in this document, fissionable material usable as the source of power when placed in a critical arrangement in a nuclear reactor. |
| fuel assembly | A single mechanical unit consisting of a number of fuel rods held together by a mechanical support structure designed to maintain proper spacing of the fuel rods and to facilitate their handling. |
| fuel burnup | See "burnup." |
| fuel cladding | See "cladding." |
| fuel consolidation | The removal of spent-fuel rods from an assembly and repacking in a denser array to reduce the volume per metric ton of fuel. See "consolidation." |
| fuel element | See "fuel assembly." |
| fuel rod | A long, slender, cylindrical tube (usually made of stainless steel or Zircaloy) containing nuclear fuel in the form of uranium oxide fuel pellets. Also called "fuel pin." |
| gamma-gamma density log | See "formation density log." |
| gamma radiation | Electromagnetic ionizing radiation that is emitted from a nucleus during some types of radioactive decay processes. Gamma radiation can penetrate various thicknesses of absorbing material, depending primarily on the energy of the gamma ray and the composition of the material. Gamma radiation is primarily an external radiation hazard. |
| gamma ray log | A radioactivity log obtained by recording the natural radioactivity of the rocks traversed by a cased or uncased borehole or well, and expressed by measuring the intensity of naturally emitted gamma rays and plotting the data as a function of depth. |

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| gamma-ray spectrum log | The radioactivity log curve of the intensity of broad-spectrum undifferentiated natural gamma radiation emitted from the rocks in a cased or uncased borehole. It is used for correlation and for distinguishing shales (which are usually richer in naturally radioactive elements) from sandstones, carbonates, and evaporites. |
| gangue | A valueless rock or mineral aggregate in an ore; that part of an ore that is not economically desirable, but cannot be avoided in mining. |
| gap-grain boundary inventory | Portions of the radionuclides in spent fuel that are segregated in part from the matrix and exist in concentrations higher than those found in the matrix, at the location of the grain boundary or between the fuel pellet and cladding. |
| gas chromatograph-mass spectrometer (GCMS) | An analytical technique that interfaces a gas chromatograph with a mass spectrometer. This technique utilizes the separation capabilities of the gas chromatograph such that the separated phases can be analyzed by the mass spectrometer. The resulting mass spectrum contains information on the structure of organic compounds and mixtures of organic compounds. This technique is also useful in detecting isotopes used in tracer studies. |
| gas drive | A process for recovering fluid from a porous rock, either in situ or in the laboratory, in which injection of a gas at elevated pressures is used to displace the fluid. The method is commonly applied in recovering oil from petroleum reservoirs after pumping becomes unproductive. |
| gas tracer test | A test in which slowly moving air currents can be directly observed by using smokes. These may range from simple dust clouds, through various chemical smokes, to more refined techniques employing gas and radioactive tracers. |
| general siting guidelines | Technical criteria established by the U.S. Department of Energy to be used in the site selection process. |
| geodetic survey | Survey in which account is taken of the figure and size of the earth and corrections are made for earth curvature. |
| geodetic trilateration | Determining the relative position of points on the on the earth's surface by using a method of surveying in which the lengths of the three sides of a series of touching or overlapping triangles are measured and the angles are computed from the measured lengths. |

**geologic disposal system (GDS)** — See "mined geologic disposal system."

**geologic repository** — A system requiring licensing by the U.S. Nuclear Regulatory Commission used for the disposal of radioactive wastes in excavated geologic media. A geologic repository includes (1) the geologic repository operations area and (2) the portion of the geologic setting that provides isolation of the radioactive waste and is located within the controlled area.

**geologic repository operations area** — A high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas and facilities, where waste-handling activities are conducted.

**geopetal structure** — Pertaining to any rock feature that indicates the relation of top to bottom at the time of formation of the rock.

**geophone** — See "seismometer."

**geosyncline** — Large, generally linear trough that subsided deeply throughout a long period of time during which a thick sequence of stratified sediments accumulated.

**geothermal gradient** — The change in temperature of the earth with depth expressed either in degrees per unit depth, or in units of depth per degree.

**geothermometer** — A mineral or mineral assemblage whose composition, structure, or inclusions are fixed within known thermal limits under particular conditions of pressure and composition and whose presence denotes a limit or range for the temperature of formation of the enclosing rock.

**geotomography** — A geophysical technique for acquisition and analysis of data in order to image the internal characteristics of a rock sample or in situ rock mass, using measurements made externally to the sample or from shafts and boreholes.

**geotransport** — Movement of radionuclides through subsurface soils and rocks, especially the movement of radionuclides in ground water.

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| gouge (fault gouge) | Soft, uncemented pulverized clayey or claylike material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault, and filling or partly filling a fault zone; a slippery mud that coats the fault surface or cements the fault breccia. A gouge is formed by the crushing and grinding of rock material as the fault developed, as well as by subsequent decomposition and alteration caused by underground circulating solutions. |
| gradation | The proportion of material of each particle size, or the frequency of distribution of various sizes, constituting a particulate material such as a soil, sediment, or sedimentary rock. The limits of each size are chosen arbitrarily. |
| grain density | Density of the solid components of a rock. |
| gravimeter log | A record of the gravity effects in boreholes to determine average rock densities. |
| gravitational potential | The amount of work that must be done to move a particle of unit mass to a specified position from a reference position. |
| gravity anomaly | The difference between the observed value of gravity at a point and the theoretically calculated value. It is based on a simple gravity model, usually modified in accordance with some generalized hypothesis of variation in subsurface density as related to surface topography. |
| gravity survey | Measurements of the gravitational field at a series of different locations. The object is to associate variations with differences in the distribution of densities and hence rock types. |
| greatest potential adverse impact | The maximum dose to an individual at the nearest unrestricted location. Equals the dose to the "maximum individual." |
| gross thermal loading | The total waste heat generation divided by the gross area of the repository. See "areal power density." |
| ground magnetic | A determination of the magnetic field at the surface of the earth by means of ground-based instruments. |
| ground surface infrared radiation | Electromagnetic radiation lying in the wavelength interval from about 0.8 microns to an indefinite upper boundary sometimes arbitrarily set at 1,000 microns. Bounded by visible radiation at its lower limit and microwave radiation at its upper limit. |

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| ground truth | Data collected at ground sites used to verify or refute remote sensing data. |
| ground water | All subsurface water as distinct from surface water. |
| ground-water sources | Aquifers that have been or could be economically and technologically developed as sources of water in the foreseeable future. |
| groundmass | The material between the larger conspicuous crystals in an igneous rock. |
| grout curtain | An area into which grout has been injected to form a barrier around an excavation or under a dam through which ground water flows at a reduced flow. |
| guideline | A statement of policy or procedure that may include, when appropriate, qualifying, disqualifying, favorable, or potentially adverse conditions as specified in the "guidelines." |
| guidelines | Part 960 of Title 10 of the Code of Federal Regulations--General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories. |
| hackly fracture | The property of a fracture or break along jagged surfaces as shown by certain minerals or rocks. |
| half-closure stress | The stress applied perpendicular to a fracture, required to reduce the unstressed aperture by half. |
| Harden Profile Index | A numerical soil index that relates 10 soil properties for each soil horizon. It is used to estimate ages of deposits or geomorphological events, and to condense descriptive field data to a numerical scheme that depicts the overall development of the soil profile. |
| headframe | The steel or timber frame at the top of a shaft that supports the sheave or pulley for the hoisting cables and serves various other purposes. |
| heat of hydration | The quantity of heat liberated or consumed when a substance takes up water. |
| heat-dissipation probe | An instrument used to measure matric potential in unsaturated rock. |
| heat pulse log | The record produced by a geophysical tool for measuring small amounts of axial flow in a borehole. The tool is typically stationed at a fixed depth, energized so as to heat a small volume of borehole fluid, and monitored to detect passage of heated fluid at detectors on the tool. |

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| heavy liquid | In analysis of minerals, a liquid of high density (1) in which specific-gravity tests can be made or (2) in which mechanically mixed minerals can be separated. |
| high-angle fault | A fault with a dip greater than 45 degrees. |
| high-level radioactive waste | The highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived form such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation. |
| higher-level finding | Finding that must be made for each qualifying and disqualifying condition of the U.S. Department of Energy's siting guidelines (10 CFR Part 960) at or before the repository site selection decision point. Higher-level findings are Level 2 or Level 4 findings, which are defined in 10 CFR Part 960, Appendix III. |
| highly populated area | Any incorporated place (recognized by the decennial reports of the U.S. Bureau of the Census) of 2,500 or more persons, or any census-designated place (as defined and delineated by the Bureau) of 2,500 or more persons, unless it can be demonstrated that any such place has a lower population density than the mean value for the continental United States. Counties or county equivalents, whether incorporated or not, are specifically excluded from the definition of "place" as used herein. |
| horst | An elongated, relatively uplifted crustal unit or block that is bounded by faults on its long sides. |
| host rock | The geologic medium in which radioactive waste is emplaced. (At Yucca Mountain, the likely host rock will be the welded tuff of the Topopah Spring Member of the Paintbrush Tuff.) |
| hot cell | A facility that allows remote viewing and manipulation of radioactive substances. |

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| hot-wire anemometer flow meter | Device for measurement of very low air velocities and the fluctuating velocities that occur in turbulent flow. Basically, it consists of a wire or wires, usually platinum, supported in a frame and heated electrically. When exposed to an air current the heated wires cool, and as a result its electrical resistance alters. Measurements of resistance change may be correlated with the velocity of the air flow that caused the change. |
| human interference | Actions of humans in the future that could interfere with isolation of radioactive materials placed in a repository. Includes direct contact with waste, such as drilling of wells or sinking of shafts and withdrawal of contaminated water or rock materials. |
| human interference (inadvertent) | The result of future human activities that inadvertently modifies the ability of a mined geologic disposal system to effectively isolate waste through the modification of the baseline hydrologic, geochemical, or rock characteristics. Includes activities such as extensive ground-water withdrawal or irrigation near the controlled area boundary. |
| human intrusion | Human activities conducted at the site that inadvertently result in direct contact with waste materials, or the creation of pathways to the accessible environment (i.e., exploratory drilling). |
| hydraulic barrier | A natural or artificial obstacle (e.g., a dike or fault gouge) to the movement of ground water. |
| hydraulic bulk conductivity | Conductivity of bulk rock mass. |
| hydraulic conductivity | The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of the flow. |
| hydraulic conductivity ellipsoid | A three-dimensional ellipse in which the square roots of the values of the principal hydraulic conductivities are the major axes. The hydraulic conductivity ellipsoid is used to graphically determine the conductivity value for any direction of flow in an anisotropic medium. |

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| hydraulic fracturing | The fracturing of a rock in a fluid reservoir by pumping in water (or other fluid) and sand (or other granular material) under high pressure. The purpose is to produce artificial openings in the rock in order to increase permeability or to measure the secondary stresses in situ. The pressure opens cracks and bedding planes, and the sand introduced into these cracks serves to keep them open when the pressure is reduced. |
| hydraulic gradient | A change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction. |
| hydraulic head | The height above sea level to which a column of water can be supported by the static pressure at that point. The total hydraulic head is the sum of elevation head (elevation above an arbitrary location) and pressure head. |
| hydraulic-stress test | Any procedure in which stresses (by pumping, injection, slugging, etc.) are imposed on an aquifer in order to evaluate its transmissive and/or storage properties. |
| hydrochemical facies | The diagnostic chemical character of ground-water solutions occurring in hydrologic systems. It is determined by the flow pattern of the water and by the effects of chemical processes operating between the ground water and the minerals within the lithologic framework. |
| hydrodynamic dispersion | The velocity distribution due to laminar flow through the pores combined with the effect of tortuous flow paths. |
| hydrofrac | See "hydraulic fracturing." |
| hydrofracture measurement | A method for measuring secondary principal stresses in situ by inducing artificial fractures. See "hydraulic fracturing." |
| hydrogen index log | See "neutron log." |
| hydrologic balance | The relative states of inflow, outflow, and storage of moisture over a given area of the earth's surface. |
| hydrologic tracejector | A geophysical tool for measuring axial flow in a borehole. The tool is typically stationed at a fixed depth, then caused to eject a small amount of miscible fluid containing a radioactive tracer, into the borehole fluid. The tool is then monitored to detect passage of the tracer at detectors on the tool. |

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| hydrometer analysis | A method to determine the particle-size distribution of a sediment consisting of silt-size or finer particles. |
| hydrosphere | The aqueous envelope of the earth, including the ocean, all lakes, streams, and underground waters, and the water vapor in the atmosphere. |
| hygrometer | An instrument that is used to measure the humidity of the air. |
| Hypalon | Brand name for an impermeable synthetic fabric manufactured by Du Pont. |
| hypocenter | The focus or specific point at which initial rupture occurs in an earthquake. |
| ice shelves | Floating ice permanently attached to a land mass. |
| imbricate thrusts | A set of nearly parallel and overlapping fault planes characterized by rock slices that are approximately equidistant and have the same displacement. |
| impedance | The product of seismic velocity and density. |
| incision | The process whereby a downward-eroding stream deepens its channel or produces a narrow steep-walled valley. Especially the downcutting of a stream during, and as a result of rejuvenation, whether due to relative movement (uplift) of the crust or other cause. |
| indirect tensile strength test | See "Brazil test." |
| indirect test | See "Brazil test." |
| induced polarization | The production of a double layer of charge at a mineral interface, or production of changes in double layer density of a charge, brought about by application of an electric or magnetic field. |
| induction electrical survey (IES) | An electric-log curve obtained in an uncased borehole by transmitting coils (led with a constant alternating current) that induce concentric eddy currents in the rocks surrounding the borehole. These in turn induce fields that are detected by receiver coils. The magnitude of the fields is proportional to the conductivity of the surrounding rocks, and the log gives a continuous record of conductivity with depth. |

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| inductively coupled plasma (ICP) spectroscopy | An analytical method that uses inductively coupled plasma to convert the sample solution to an atomic vapor for analysis with a multichannel analyzer. This method provides a rapid means of chemically analyzing solutions and provides multi-element analytical data rather than data on a single element, as is the product of atomic absorption spectrometry. |
| industrial minerals | Any rock, mineral, or other naturally occurring substance of economic value, exclusive of metallic ores, mineral fuels, and gemstones; one of the nonmetallics. |
| information needs | (1) The lowest level of the issues hierarchy for performance and design issues. They comprise requirements for additional data or analyses about particular natural conditions or design elements. (2) Additional information needed to satisfy information requirements, (i.e., information requirements minus available relevant information) and thereby demonstrate compliance with regulations, etc. |
| ingestion-dose pathway | Those components of the food chain or water system that might contribute to the radiation exposure of an individual as the result of an intake of food or water. |
| inoculate | To implant microorganisms into a culture medium. |
| insolation | Protection against direct solar radiation provided by Earth's atmosphere. |
| institutional controls | Administrative controls, records, physical constraints, and combinations thereof that would limit intentional or inadvertent human access to the waste emplaced in a repository. |
| instrumental neutron activation analysis (INAA) | A technique for the trace element analysis of rocks and minerals using a sample that has been bombarded with neutrons in a reactor. From the identities of the radioisotopes, the identities of the parent elements in the sample can be determined. The quantity of the parent element can then be calculated. |
| interbasin flow | The flow of water between adjacent surface or groundwater basins. |
| interface zone (hydrology) | The contact zone between two fluids of different chemical or physical makeup. |

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| interflow (water storm seepage) | The runoff (water) infiltrating the surface soil and moving toward streams as ephemeral shallow perched ground water above the main ground-water level. Interflow is usually considered part of direct runoff. |
| interfluve | The relatively undissected upland between adjacent streams flowing in the same general direction. |
| interglacial | Pertaining to or formed during the time interval between two successive glacial epochs or between two glacial stages. |
| intermittent stream | A stream that flows only periodically, as, after a rainstorm, during wet weather, or during part of the year. |
| internal drainage | Surface drainage in which the water does not reach the ocean, such as drainage toward the central part of an interior basin. |
| intrinsic dispersion | The variation with frequency of seismic velocity in an elastic material because of variations in the elasticity. Distinguished from the geometric dispersion associated with the physical configuration of the material. |
| intrinsic permeability (specific permeability) | Pertaining to the relative ease with which a porous medium can transmit a liquid under a hydraulic or potential gradient. It is a property of the porous medium and is independent of the nature of the liquid alone. |
| intrusion (igneous) | (1) The process of emplacement of magma in pre-existing rock, (2) magmatic activity, or (3) the igneous rock so formed within the surrounding rock. |
| inverse problem | The problem of gaining knowledge of the physical features of a disturbing body by analysis of its effects. Finding the model from observed data. |
| ion chromatography | A term referring to analytical techniques that involve the chromatographic separation of ions utilizing high performance separation technology and automatic detection systems. The techniques involved usually employ ion exchange column systems using detection systems such as conductivity detectors or electrochemical detectors in a continuous flow system. Generally, this technique is used for separating and quantifying ions with pKa values greater than 7. |

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| ion-microprobe | An instrument that uses a focused beam of ions that, in striking the surface of a sample, produces a resulting emission of ions from the surface of the sample. These ions are collected and analyzed. This technique complements the electron microprobe technique by providing information on the concentration and distribution of isotopes of the elements in the surface of a solid. This technique can handle detection of elements lighter than sodium, which generally is the limit of the electron microprobe. |
| ionic strength | A measure of the average electrostatic interactions among ions in a solution; it is equal to one-half the sum of the terms obtained by multiplying the molality of each ion by its valence squared. For a simple salt like $KNO_3$, the ionic strength is equal to its concentration. For a mixture of $KNO_3$ with $AgIO_3$, the ionic strength varies as a function of the concentration of each salt. |
| ionizing radiation | Any radiation (e.g., alpha, beta, and gamma radiation) displacing electrons from atoms or molecules, thereby producing ions. |
| irreversible reaction | A reaction that proceeds in one direction. |
| island arc | A chain of islands usually with a curving archlike pattern, generally convex toward the open ocean, having a deep trench or trough on the convex side and usually enclosing a deep basin on the concave side. They are usually affiliated with subduction zones. |
| isolation | The inhibiting of the transport of radioactive material so that the amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits. |
| isolation barrier | The earth material around the underground disposal rooms; it acts to prevent radioactivity from entering the biosphere. |
| isometric | Used to describe minerals that form within the crystallographic system and whose structure is that of three equal and mutually perpendicular axes. |

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| isostatic anomaly | The (1) observed Bouguer anomaly, corrected for the isostatic compensation that is theoretically required to support the weight of topographic features on the earth's crust; or (2) the density deficiency associated with the oceans. The isostatic compensation correction is calculated by assuming that the total weight per unit area of any column of crustal material is the same if the bottom of the column is taken at a particular compensation depth (Pratt model or density contrast (Airy model)). |
| isotopic dating | See "radiometric dating." |
| isotopic exchange | A process whereby atoms of the same element in two different molecules or in different sites in the same molecule exchange places. The equilibrium in such an exchange reaction is influenced slightly by the relative masses of the two atoms which exchange; the process forms the basis of one of the methods of isotope separation and concentration. |
| issue | A question relating to the performance of the mined geologic disposal system that must be resolved to demonstrate compliance with the applicable Federal regulations (including 10 CFR Part 60, 10 CFR Part 960, 40 CFR Part 191, and 10 CFR Part 20). See Section 8.1.1. |
| joint | A surface of fracture or parting in a rock, without displacement. |
| kataseism | Earth movement toward the focus of an earthquake. |
| Kelvin equation | An equation giving the increase in vapor pressure of a substance that accompanies an increase in curvature of its surface; the equation describes the greater rate of evaporation of a small liquid droplet compared with that of a larger one, and the greater solubility of small solid particles compared with that of larger particles. |
| key | To establish a mechanical bond in a construction joint to stabilize the rock mass. |
| key block analysis | A method of analysis for estimating support requirements for underground openings, using a topological treatment of rock-mass joint orientations. |

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| kinematic | The analysis of displacements and strains; it is based on geometric analysis plus a number of assumptions regarding the manner in which geometrical relationships serve to indicate displacements. |
| kinetics | A branch of science that deals with the effects of forces upon the motions of material bodies or with changes in a physical or chemical system. |
| Klinkenberg permeability (factor) | A factor indicating the dependence of measured permeability of a porous medium to gas pressure. This permeability is larger than that of a liquid because of the slip phenomenon in which the velocity of a gas layer in the immediate vicinity of the surface of the grains is finite in contrast of the zero velocity of a liquid. |
| Kriging | A statistical procedure that uses information from the degree of spatial continuity of a regionalized variable to find an optimal set of weighting factors that are used in the estimation of a geologic surface at the unsampled points. The method also provides measures of the uncertainty of the estimate. |
| lagging | Heavy planks or timbers for supporting the roof of a mine for floors of working places, and for the accumulation of rocks and earth in a stope. |
| laminations | The finest stratification or bedding typically exhibited by shales and fine-grained sandstones. |
| Landsat V Thematic Mapper imagery | Multispectral scanner remote sensing imagery from the Landsat V satellite. |
| Langmuir isotherm | A mathematical model representing the partitioning of solutes between liquid and solid phases in experiments. It is commonly expressed in two-ordinate graphical form where mass sorbed per unit mass of dry solids is plotted against the concentration of the constituent in solution. |
| lanthanides | Any element in a series of elements of increasing atomic numbers beginning with lanthanum (57) or cerium (58) and ending with lutetium (71). |
| lapse rates | The decrease in an atmospheric variable with height; the variable is temperature unless otherwise specified. |
| lateral faulting | A fault in which the net slip is practically in the direction of the fault strike. |
| lateral flow | Any flow where the major flow component is horizontal. |

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| lateral offset | The horizontal distance one fault block moves in relation to the other. |
| leakance (leakage coefficient) | The quantity of water that flows across a unit area of the boundary between the main aquifer and its overlying or underlying semiconfining layer per unit head difference across this semiconfining layer. |
| lenticle | A small lentil. |
| lentil | A minor rock-stratigraphic unit of limited geographic extent, being a subdivision of a formation and similar in rank to a member, and thinning out in all directions. |
| license application | An application for a license from the U.S. Nuclear Regulatory Commission to construct a repository. |
| license application design | The design phase that completes the resolution of design and licensing issues identified and assessed in earlier design phases and will develop the design of the items necessary to demonstrate compliance with the design requirements and performance objectives of 10 CFR Part 60. Design requirements resulting from safety and reliability analyses will be fully integrated in this design to support the safety analysis report. |
| licensing | The process of obtaining the permits and authorizations required to site, construct, operate, close, and decommission a repository. |
| licensing assessment | An assessment of whether a license application complies with all of the requirements that it purports to meet. For this program it is the sum of the individual findings for each of the requirements of 10 CFR 60. |
| ligand | A group, ion, or molecule coordinated to a central atom in a complex. |
| light water reactor (LWR) | A nuclear reactor that uses ordinary water as a moderator, in contrast to heavy water (a compound of hydrogen and oxygen containing a higher proportion of the hydrogen isotope deuterium). |
| linear energy transfer (LET) | A measure of the energy deposited by ionizing radiation per unit of path length. The quality factor used in determining dose equivalent is based on the LET. |

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| linear expansion | The change in linear dimension of a solid resulting from the change in temperature. The coefficient of linear expansion is the change in a solid's unit linear dimension per 1 degree change in temperature. |
| linear variable differential transformer | Sensor used to measure displacements and relate them to changes in electrical outputs. |
| lineation | A general, nongeneric term for any linear structure in a rock (e.g., flow lines, slikensides, linear arrangements or components in sediments, or axes of folds). |
| liner | See "emplacement borehole liner." |
| liquefaction | In cohesionless soil, the transformation from a solid to a liquid state as a result of increased pore pressure and reduced effective stress. |
| liquid penetrant testing | A penetrant method of nondestructive testing used to locate defects open to the surface of nonporous materials; penetrating liquid is applied to the surface and after 1 to 30 minutes excess liquid is removed, and a developer is applied to draw the penetrant out of defects, thus showing their location, shape, and size. |
| listric surface | A curvilinear, usually concave-upward surface of a fracture or fault that curves, at first steeply then more gently, from a horizontal position. Listric surfaces bound wedge-shaped masses and appear to be thrust against or along each other. |
| lithophysae | Bubblelike structures in rocks, generally hollow, composed of concentric shells of finely crystalline alkali feldspar, quartz, and other materials. |
| lithostatic load | The force exerted on an object or underground structure by the weight of overlying material in the lithosphere. |
| lithostatic pressure | The stress to which a rock formation is subjected by the weight of the overlying rocks in the lithosphere. |
| load cell | A strain-gaged cylinder or cell that can be calibrated to measure compressive loads directly. |

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| local magnitude ($M_L$) | The logarithm of the amplitude of an earthquake wave with a 1-s period measured exactly 100 km away from the earthquake. This mathematical relationship holds only for shallow focus events, and a correction factor must be added if the amplitude of the wave is not recorded at a position exactly 100 km away from the event. |
| logging cable | A survey cable or hoist cable containing one or more insulated electrical conductors enclosed in a tightly wrapped sheath of steel wires. |
| logging sondes | A downhole device containing the measuring instrument in logging a well or borehole, which is lowered on a logging cable (wire line) (e.g., a circular container used in electric logging and in which the electrode devices are set). |
| logistic regression | A regression analysis for sparse data using a maximum likelihood method. |
| loss of containment | The time at which the ensemble of waste packages first fails to conform to the numerical interpretation of "substantially complete containment." |
| low-angle fault | A fault with a dip of 45 degrees or less. |
| low-level waste (radioactive) | Radioactive material that is neither high-level radioactive waste, spent nuclear fuel, transuranic waste, nor byproduct material as defined in Section 11a(2) of the Atomic Energy Act of 1954. |
| lower-level finding | A finding that must be made for each qualifying and disqualifying condition of the U.S. Department of Energy's Siting Guidelines (10 CFR Part 960) at or before the site nomination and recommendation decision point. Lower level findings are Level 1 or Level 2 findings, which are defined in 10 CFR Part 960, Appendix III. |
| lysimeter | A structure used to measure quantities of water used by plants, evaporated from soil, and lost by deep percolation. It consists of a basin, having closed sides and a bottom fitted with a drain, in which soil is placed and plants are grown. Quantities of natural and artificial precipitation are measured, the deep percolate is measured and analyzed, and the water taken up by the plants is weighed. |
| macroscopic continuum approach | See "continuum theory." |

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| magnetic log | Record of the magnetic susceptibility of the rocks surrounding a borehole using electromagnetic induction. |
| magnetic particle testing | A nondestructive method of inspection for determining the existence and extent of possible defects in ferromagnetic materials. Finely divided magnetic particles applied to the magnetized part are attracted to and outline the pattern of any magnetic leakage fields created by discontinuities. |
| magnetic polarity time scale | A chronology based on counting reversals of the earth's magnetic field. |
| magnetic survey | A survey made with a magnetometer on the ground or in the air that reveals local variations, or anomalies, in the total intensity, component intensity, or component direction of the earth's magnetic field. |
| magnetic susceptibility | The ratio of induced magnetization to the strength of the magnetic field causing magnetization. |
| magneto-stratigraphy | All parts of stratigraphy based on paleomagnetic signatures. |
| magnetotelluric (MT) method | An electromagnetic method of surveying in which natural electric and magnetic fields are measured. Usually the two horizontal electric-field components plus the three magnetic-field components are recorded. |
| main | One of the three main drifts that run from the base of the two ramps and men-and-materials shafts through the underground facility to provide access to the waste emplacement panels. See "tuff main," "service main," and "waste main." |
| man-rem | A unit used in health physics to compare the effects of different amounts of radiation on groups of people. It is obtained by multiplying the average dose equivalent to the whole body or a given organ or tissue (measured in rems) by the number of persons in that population. |
| mantle | The zone of earth below the crust and above the core, which is divided into the upper mantle and the lower mantle, with a transition zone between. |
| marker bed | A geologic formation that is distinctive and easily recognized over long distances, especially in the subsurface. |
| mass conservation | The physical principal that mass cannot be created or destroyed in the absence of fission or fusion. |

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| mass spectrometer | An instrument that is composed of an (1) inlet system, (2) ion source, (3) electrostatic accelerating system, and (4) detector and readout-system. This instrument produces charged particles consisting of the parent ion and ion fragments of the original molecule and sorts these ions according to their mass-to-charge ratios (mass spectra). |
| mass spectrometry | An analytical technique that uses a mass spectrometer to produce a mass spectrum of the ions, molecules, functional groups, etc., present in the sample. The mass spectra are used to identify the structure of organic compounds and in analyzing complex organic mixtures. |
| mass transfer kinetics | The process study of the kinetics of sorption as a function of water velocity. The adsorption of sorption radionuclides is a dynamic process and has a reaction kinetics rate. This process study evaluates the kinetic limitations of sorption in an advective system. |
| mass wasting | A general term for the downslope movement of soil and rock material under the direct influence of gravity. The debris removed is not carried within, on, or under another medium. |
| massif | Body of intrusive igneous or metamorphic rock at least 10 to 20 miles in diameter occurring as a structurally resistant mass in an uplifted area that may have once been a mountain core. |
| matrix | Relatively fine-grained material in which coarser fragments or crystals are embedded; also called groundmass. |
| matrix diffusion | The movement of dissolved species from water in the connected pore space to water in the dead end pore spaces by the action of gradients in species concentration. In particular, the connected pore spaces may be fracture networks and the dead end pore spaces may be matrix pores. |
| maximally exposed individual | See "maximum individual." |
| maximum individual | A hypothetical member of the public whose habits, activities, and location tend to maximize the radiological dose received from some given operation. |

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| maximum individual dose | The highest radiation dose delivered to the whole body or to an organ that a person can receive from a release of radioactivity. The hypothetical person who receives this dose is referred to as the maximally exposed individual. |
| maximum permissible concentrations | The average concentration of a radionuclide in air or water to which a worker or member of the general population may be continuously exposed (40 hours per week only for workers) without exceeding regulatory limits on external or internal radiation doses. Specified in Appendix B of 10 CFR Part 20. |
| mechanical | A term applied to the material properties that govern the physical response of a material to applied physical stress or to the analysis of that response (e.g., mechanical properties, mechanical analysis). |
| mechanical dispersion | A microscopic mixing process caused entirely by the motion of fluid in a porous medium. |
| melange terrain | Composed of a heterogeneous mixture of rock material. Specifically, a mappable body of deformed rocks consisting of a pervasively sheared, fine-grained, commonly pelitic matrix, thoroughly mixed with angular and poorly sorted inclusions of native and exotic tectonic fragments, blocks, or slabs. |
| Mercalli intensity | A scale for measuring earthquake intensity in terms of the effects perceived by people near the earthquake. |
| mercury injection method | A method used for determining the porosity of a rock sample. |
| mesostasis | The last-formed interstitial material of an igneous rock. |
| metallogenic provinces | An area characterized by a particular assemblage of mineral deposits, or by one or more characteristic types of mineralization. A metallogenic province may have had more than one episode of mineralization, or metallogenic epoch. |
| metamorphic grade | The intensity or rank of metamorphism, measured by the amount or degree of difference between the original parent rock and the metamorphic rock. |
| metasomatic | The process by which one mineral is replaced by another of different chemical composition owing to reactions set up by the introduction of material from external sources. |

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| metastable | Pertaining to a body or system existing at an energy level above that of a more stable state and requiring the addition of a small amount of energy to induce a transition to the more stable state. |
| metastable (radionuclide) | A state of temporary nuclear stability that occurs in some types of radioactive decays. During these decays (called isomeric transition), an intermediate product is formed by the first stage of decay. This product has a half-life long enough to be considered a separate isotope. |
| meteoric water | (1) Water occurring in or derived from the atmosphere. (2) Pertaining to water of recent atmospheric origin. |
| mined geologic disposal system (MGDS) | A system, requiring licensing by the U.S. Nuclear Regulatory Commission, that is used for the disposal of high-level radioactive waste in excavated geologic media. It is synonymous with "geologic repository." |
| mineral assemblages | The minerals that compose a rock, especially an igneous or metamorphic rock. The term includes the different kinds and relative abundances of minerals, but excludes the texture and fabric of the rock. |
| mineral paragenesis | A general term for the order of formation of associated minerals in time succession, one after another. |
| mineral stability | The tendency of a mineral species to remain unaltered under the conditions of temperature and pressure currently experienced. |
| mini-sosie (shallow seismic reflection) | A method of acquiring and analyzing seismic reflection data to image the subsurface. One or more tamping-type vibrators are used in conjunction with a geophone array. Deconvolution of the recorded wavetrains is required to eliminate the signature of the source vibrators. |
| miogeosyncline | A geosyncline in which volcanism is not associated with sedimentation. |
| mitigation | (1) Avoiding an impact altogether by not taking a certain action or parts of an action, (2) minimizing impacts by limiting the degree or magnitude of the action and its implementation, (3) rectifying an impact by repairing, rehabilitating, or restoring the affected environment, (4) reducing or eliminating an impact over time by preservation and maintenance operations during the life of the action, or (5) compensating for the impact by replacing or providing substitute resources or environments. |

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| mixing height (or depth) | The height above the surface of the earth defining a layer where vigorous vertical mixing occurs; this mixing layer represents the vertical extent to which pollutants can be mixed in the atmosphere. |
| modal petrography | The analysis of the actual mineral composition of a rock, usually expressed in weight or volume percentages. |
| modified Mercalli scale | An earthquake intensity scale having 12 divisions ranging from I (not felt by people) to XII (damage nearly total), commonly abbreviated MM. |
| modified permeability zone (MPZ) | The zone immediately surrounding an underground excavation in which the permeability of the rock mass has been altered due to stress redistribution and blast damage effects. |
| modulus of deformation | Experimentally determined coefficient of proportionality relating applied stress to observed strain. |
| modulus of elasticity | See "elastic modulus." |
| modulus of rupture | The maximum tensile stress in a sample undergoing bending, or the maximum shear stress in a sample undergoing torsion, corresponding to peak load. |
| modulus of subgrade | See "modulus of subgrade reaction." |
| modulus of subgrade reaction | Coefficient of proportionality (Cp) in the empirical expression: $P_s = (Cp)(S)$, where $P_s$ is the soil pressure and S is equivalent to the settlement resulting from external pressure. |
| Mohorovicic Discontinuity | The boundary surface that marks a rapid change in seismic velocity. It marks the level at which P-wave velocities change abruptly. Its depth ranges from about 5 to 10 km beneath the ocean floor to about 35 km below the continents, although it may reach 60 km or more under some mountain ranges. It is variously estimated to be between 0.2 and 3 km thick. |
| Mohr-Cohlomb criterion | A criterion of failure for solid material undergoing loading, relating peak stress conditions to confining pressure. May be used for intact material, or used to represent the minimum "residual" strength reached by a material subjected to deformation beyond the peak. |

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| moisture-retention curve | A graph showing the percentage of soil moisture (by mass or volume) versus applied tension. |
| molecular diffusion | Macroscopic transport of mass, independent of any convection within the system. |
| molecular sieve | A term used to describe the function of zeolite materials, which are clay-like in chemical nature, and from which all water can be removed without alteration of their molecular structure. As a result of this, the material becomes microporous to such an extent that about half its volume is occupied by very small holes or channels. The material thus readily adsorbs molecules that are small enough to enter the pores vacated by the water molecules. Zeolites therefore act as selective devices that adsorb smaller molecules readily but exclude larger ones. For this reason, they are called molecular sieves. |
| molecular-sieve adsorption | The removal of a solute particle from a solution as the solution is forced through a material whose molecular structure is such that its physical arrangement precludes the passing of (and thus traps) the solute particle. |
| moments (statistical) | In general, the mean value of a power of a variate. |
| Monte Carlo simulation | A random-sampling process for generating uniformly distributed pseudorandom numbers and using these to "draw" random samples from known frequency distributions. |
| morphometric analysis | The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms. The main aspects examined are the area, altitude, volume, slope, profile, and texture of the land as well as the varied characteristics of rivers and drainage basins. |
| morphotectonics | The tectonic interpretation of the morphological or topographic features of the earth's surface. It deals with their tectonic or structural relations and origins, rather than their origins by surficial processes of erosion and sedimentation. |
| motile | Exhibiting or capable of movement. |
| muck | Broken rock or ore that results from excavation during mining operations. |

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| mud cake | The material filling the cracks, crevices, pores, etc. of the rock or adhering to the walls of the borehole. The cake may be derived from the drill cuttings, circulating drill mud, or both. It is formed when the water from the drilling mud filters into porous formations, leaving the mud ingredients as a caked layer adhering to the walls of the drillhole. |
| multibarrier system | A system of natural and engineered barriers, operating independently or relatively independently, that acts to contain and isolate the waste. |
| multidetector compensated gamma-gamma tool | See "formation density log with dual proximity." |
| multidetector compensated neutron porosity tool | See "neutron borehole compensated log." |
| multiple point borehole extensometer (MPBX) | An instrument placed in boreholes, drilled in walls of mined openings and tunnels and used to measure relative displacement changes parallel to the borehole axis in response to excavation or other loading of rocks in response to excavation or changes in the stress field. |
| multiwell aquifer test | A test to determine an aquifer's capacity; it involves adding or withdrawing measured quantities from more than one well and measuring the resulting changes in hydraulic head. |
| mylonite | A deformed rock or texture with a streaky or banded structure produced by shearing of rocks. Often used as a sense-of-shear indicator. |
| natural background radiation | The radiation that occurs naturally in the environment from such sources as cosmic rays, the naturally occurring radioactive elements in the earth, and naturally occurring radionuclides in living organisms (different from "background radiation"). |
| natural barrier | The physical, mechanical, chemical, and hydrologic characteristics of the geologic environment that individually and collectively act to minimize or preclude radionuclide transport. |
| natural gamma log | A geophysical wireline method whereby a gamma radiation detector such as a scintillation counter is used in a borehole to record the variation of natural gamma activity with depth. |

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| natural system | A host rock suitable for repository construction and waste emplacement and the surrounding rock formations. Includes natural barriers that provide containment and isolation by limiting radionuclide transport through the geohydrologic environment to the biosphere and provide conditions that will minimize the potential for human interference in the future. |
| near-field | That portion of the rock surrounding emplaced waste in which analysis of the thermal and thermomechanical effects of the waste must consider the specific geometric characteristics of the underground facility, including borehole size and orientation, standoff distance, drift shape dimensions and spacing, or overall layout of the facility. |
| neotectonics | The study of the post-Miocene structures and structural history of the earth. |
| net infiltration | The amount of precipitation that enters the unsaturated zone below the surficial root zone. |
| Neumann boundary condition | A boundary condition in which the flux normal to the boundary surface is prescribed for all points. A special case of this type of boundary is the impervious boundary where the flux normal to the boundary vanishes everywhere. |
| neutron activation analysis | A quantitative analytical technique for elemental analysis that involves the production of a radioactive isotope by the capture of neutrons by the nuclei of the substance to be analyzed. The identification of the radioactive isotopes is done by measurement of the half-life (or energy of the beta particles) or by the gamma-ray spectrum. |
| neutron borehole compensated (NBC) log (compensated log) | A well log made with a mandrell-type neutron logging tool having two neutron detectors. The neutron porosity is derived from the ratio of the counting rates of the two detectors. |
| neutron log | A radioactivity log that measures the intensity of neutrons or gamma rays produced when rocks around a borehole are bombarded by neutrons from a synthetic source. |
| neutron moisture tube | A probe lowered into an access hole used for measuring water content of soil and rocks as indicated by the scattering and absorption of neutrons emitted from a source, and the resulting gamma radiation received by a detector. |

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| neutron-neutron log (NNL) | Any of the several neutron log curves that measures the abundance of neutrons of a discrete energy range. Neutrons arrive at the detector after "random walk" scattering and slowing, most effectively by hydrogen nuclei. Depending on the neutron-energy selectivity level of the indicator, these curves may be divided into epithermal neutron log and thermal neutron log types. |
| neutron probe | A probe that measures the intensity of radiation (neutrons or gamma rays) artificially produced when rocks around a borehole are bombarded by neutrons from a synthetic source. The results are recorded on a neutron log. |
| neutron scattering | The change in direction of neutrons caused by collision with nuclei in a material. |
| neutron soil-moisture meter | See "neutron moisture tube." |
| nivation | The process of excavation of a shallow depression in a mountainside by removal of fine material around the edge of a shrinking snow patch or snowbank, chiefly through sheetwash, flow, and solution in meltwater. |
| no-flow boundary | See "Neumann boundary condition." |
| nodal plane | A plane through the earthquake focus in which no energy of the longitudinal wave kind is radiated but where transverse wave energy is at a minimum. |
| nonradiological risk | A risk from sources other than exposure to radiation. |
| normal conditions | The state or conditions expected to be present most of the time. It is generally used to indicate conditions of temperature, opening stability, equipment, etc., expected about 90 percent of the time. |
| normal fault | A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45 to 90 degrees measured from the horizontal. |
| nuclear borehole geophysical log | Log that measures and records radiations from rocks penetrated by a borehole or well. A sonde (on a wire line) is lowered and raised making measurements of radioactive properties of the rocks as a function of depth. Used in cased and uncased holes. |
| nuclear fuel cycle | Those operations associated with the production of electrical power for public use by any fuel cycle through utilization of nuclear energy. |

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| NX-sized borehole | The letter code for a 76-mm (3-in.) borehole from which a 54.8-mm (2.16-in.) diameter core is typically extracted. |
| oblique extension | Extension along a fault in which the motion is a combination of slip along the dip of the fault plane and slip that is purely horizontal. |
| observation well | A special well drilled in a selected location for the purpose of observing parameters such as fluid levels and pressure changes. |
| occupational dose | The radiation dose received by a person in a restricted area or in performing work duties involving exposure to radiation. |
| occupational exposure | The absorption of radiation or the ingestion of a radionuclide by any individual on duty and engaged in operations involving the management, storage, and disposal of radioactive waste. |
| oceanic mixed layer | The surface layer of the ocean that is well mixed by winds, waves, seasonal cooling, and salinity increases resulting from evaporation. |
| ODEX drilling method | An under-reamer type percussion drilling method that uses special tools to pull a string of casing into the hole as the hole is drilled. The under-reamer type bit provides a clearance hole for the casing, while providing a means to extract the drill string and tools. The ODEX system is often used with a downhole hammer, and may be used with various drilling fluids including mud, foam, or air alone. |
| off-normal | See "abnormal." |
| offsite | That area not under effective control of persons possessing or using spent nuclear fuel or radioactive waste. |
| ongoing activities | Site characterization activities, as defined by the Nuclear Waste Policy Act of 1982, that were in progress at the time of Presidential approval (May 1986). |
| open-system method | See "uranium-trend method." |
| operational phase | The period of time from the receipt of the first waste at the site of the repository to closure and decommissioning. |
| orbital elements | A set of seven parameters defining the orbit of a body attracted by a central inverse-square force. |

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| orogeny | The process of forming mountains, particularly by folding and thrusting. |
| orographic | Said of the precipitation that results when moisture-laden air encounters a high barrier and is forced to rise over it, such as the precipitation on the windward slopes of a mountain range facing a steady wind from a warm ocean. Also, said of the lifting of an air current caused by its passage up and over a mountain. |
| osmotic potential | The pressure that is developed across a membrane, which is permeable to the solvent but not the solute, when differing concentrations of a solute are placed in contact with opposite sides of the membrane, and flux of solvent across the membrane is not allowed. |
| outflow | Water that flows out (e.g., ground-water seepage and stream water flowing out of a drainage basin). Also, the amount of water that has flowed out. |
| out-year activities | Site characterization activities, as defined by the Nuclear Waste Policy Act of 1982, that will be initiated after the first year of site characterization. |
| overburden stress (geostatic pressure) | The vertical pressure at a point in the earth's crust, which is equal to the pressure caused by the weight of a column of the overlying rock or soil. |
| overcoring | (1) A process for determining stress components in a rock mass. The process consists of drilling a small diameter borehole and inserting deformation-sensing devices. Subsequently, a larger diameter hole is drilled concentrically with the first hole and, in doing so, relieves the stress in the rock cylinder. The measured deformations are related to stresses through elastic relationships. (2) (rock mechanics) A method of measuring in situ stress. The method involves installation of multidirectional strain recording devices in small boreholes and removing the devices by the coring and enclosing wall rock while recording the resulting strain relief. (3) The drilling of a relatively larger diameter core, encompassing a preexisting, smaller diameter hole. The larger and smaller holes need not be concentric. |
| overcoring stress | In situ stress determined by the method of overcoring. |
| overdraft | Withdrawal of ground water in excess of replenishment. |

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| overpack | Any receptacle, wrapper, box, or other structure that becomes an integral part of a radioactive waste package and is used to enclose a waste container for purposes of providing additional protection or for meeting the requirements of an acceptance or isolation criterion for a specific site. An overpack is often used to encase a damaged or contaminated waste package for which repair or decontamination is impractical. |
| oversaturated | Contains, because of its manner of preparation, more solute than normally expected under the given condition. |
| oxidation-reduction reaction | A chemical reaction in which one or more electrons are transferred between two or more chemical constituents of the system. |
| oxygen-isotope analysis | Analysis of the fractionation of oxygen isotopes (oxygen-18/oxygen-16) in oxygen-bearing geologic materials which may be used as an indication of the source or temperature of formation of the materials. |
| P-wave | See "compressional wave." |
| pack rat midden | Preserved plant remains, dung, and refuse deposited in rock cavities by rodents of the genus Neotoma and held together by dried urine. |
| packaging | The container, any overpacks and their contents, excluding radioactive materials and their encapsulating matrix but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for absorbing mechanical shock, external fittings or handling devices, neutron absorbers or moderators, and other supplementary equipment that surrounds the radioactive material. |
| packer | A removable device used in drilled holes to isolate one part of a borehole from another in order to carry out studies of particular formations or parts thereof. |
| packer tests | An in situ flow test carried out in a drillhole by isolating an interval of uncased (open) hole and injecting water or gas into the interval. The rate of inflow is measured at a range of values of constant injection pressure. The tests may be performed in some cased holes if the test interval is perforated. |

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| packer-injection tests | A variety of tests whereby a liquid (usually water) or gas is injected into a "sealed off" or isolated portion of a borehole or well to obtain data on such things as formation permeability and fracture flow parameters of rocks. |
| paleo- | A combining form denoting the attribute of great age or involving ancient conditions (e.g., paleoclimate, paleosol, paleohydrology). |
| palynology | The branch of science concerned with the study of pollen of seed plants and spores of other embryophytic plants, whether living or fossil. |
| pan evaporation data | Data collected on evaporation rates by directly measuring the drop in water level in the evaporation pan at specific time intervals. |
| panel | A nearly rectangular section of the underground layout sized to accommodate a certain amount of waste and used in planning, scheduling, and design analyses. |
| paragenesis | See "mineral paragenesis." |
| partial penetration | A well that does not fully penetrate the aquifer under development. |
| partial pressure | The pressure exerted by a specified component in a mixture of gases. |
| particle-tracking technique | A numerical procedure commonly used in calculating the dispersive transport properties of an aquifer. In practice, mathematical points or "particles" are permitted to move (1) in the direction of water flow to simulate advection, and (2) in accordance with some random statistical distribution (frequently Gaussian) to simulate dispersion. |
| particle velocity | The velocity with which an individual particle of water moves through the subsurface. |
| Pasquill stability class | See "atmospheric stability class." |
| passive institutional control | (1) Permanent markers placed at a disposal site, (2) public records and archives, (3) government ownership and regulations regarding land or resource use, and (4)other methods of preserving knowledge about the location, design, and contents of a disposal system. |

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| passive margin | In plate tectonics, movement along extensional ridges occurring in such a way as not to deform or distort the large bodies of horizontally stratified sediments lying in the continental margin. |
| Peclet number | A dimensionless quantity that measures the magnitude of advective transport relative to the magnitude of diffusive transport. |
| Peltier type thermocouple psychrometer | A water potential thermocouple psychrometer that is wetted by passing a current through the thermocouple junction, causing it to cool below the dewpoint, resulting in the condensation of water vapor on the sensing junction. |
| perched ground water | Unconfined ground water separated from an underlying body of ground water by an unsaturated zone. Its water table is a perched water table. Perched ground water is held up by a perching bed whose permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure. |
| perched spring | A spring whose source of water is a body of perched ground water. |
| perennial stream | A stream that flows throughout the year and from source to mouth; a permanent stream. |
| perennial yield (safe yield) | That rate at which water can be withdrawn from an aquifer without depleting the supply to such an extent that withdrawal at this rate is harmful to the aquifer itself, or to the quality of the water, or is no longer economically feasible. |
| performance allocation | A part of the process for developing strategies for the resolution of issues, used to guide the site characterization program. See Section 8.1.2. |
| performance assessment | Any analysis that predicts the behavior of a system or system component under a given set of constant and/or transient conditions. Performance assessments will include estimates of the effects of uncertainties in data and modeling. |
| performance confirmation | The program of tests, experiments, and analyses that is conducted to evaluate the accuracy and adequacy of the information used to determine with reasonable assurance that the performance objectives for the period after permanent closure can be met. |
| performance criterion | A criterion establishing qualitative operational, safety, or environmental limits. |

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| performance goal | A specific value assigned to a performance measure as part of the performance-allocation process. |
| performance measure | A physical quantity that describes the performance of a system, system element, structure, component, or process in meeting the licensing strategy for an issue. |
| performance objective | The predetermined standard or specification used to evaluate the acceptability of each system, structure, or component during a performance assessment. Different performance objectives may be suitable for the preclosure and postclosure periods. |
| performance parameter | In performance allocation, a physical quantity (either measurable or calculable) used to evaluate a performance measure. |
| perimeter drift | The drift that encircles the emplacement area, advancing in a clockwise direction as the emplacement area is developed. It functions as the exhaust airway for the emplacement area. |
| perlitic | The texture of a glassy igneous rock that has cracked due to contraction during cooling, the cracks forming small spheruloids. It is generally confined to natural glass, but occasionally found in quartz and other noncleavable minerals and as a relict structure in devitrified rocks. |
| permanent closure | See "closure." |
| permeability | In hydrology, the capacity of a medium (rock, sediment, or soil) to transmit ground water. Permeability depends on the size and shape of the pores in the medium and how they are interconnected. |
| permeametry | Determination of permeability of a material by passing a liquid through a sample of known dimensions and recording the pressure drop and flow rate through the bed. |
| permissible dose | That dose of ionizing radiation that, in light of present knowledge, carries negligible probability of causing a severe somatic injury or a genetic effect. |
| persistence (of discontinuity) | One of the ten parameters selected to describe discontinuities in rock masses, being the discontinuity trace length as observed in an exposure, which may give a crude measure of the areal extent or penetration length of a discontinuity. Termination in solid rock or against other discontinuities reduces the persistence. |

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| petrofabric | The actual rock fabric as analyzed on the thin-section or micro scale, including grain shapes and relationships. |
| phenocryst | A large crystal in a groundmass of smaller crystals or glass. |
| phreatophyte | A plant that consumes and then transpires inordinate amounts of water compared to xerophytes. |
| physical adsorption (physisorption) | The process by which molecules stick to a surface by van der Waals forces. In physisorption no chemical bonds are broken. The molecule is not changed in content but it may be bent or stretched in the proximity of the surface. |
| phytoliths | A discrete, distinctively shaped, minute (less than 30 microns in diameter) solid body of isotropic silica originally precipitated by terrestrial plants as unwanted material or as reinforcement or cell structures. |
| Picard iteration | A method that gives approximate solutions of an initial value problem which is of the form $y' = f(x,y)$, $y(x_o) = y_o$ and is assumed to have a unique solution on some interval containing $x_o$. |
| piezometer | An instrument for measuring the change of pressure of a material subjected to hydrostatic pressure. |
| piezometric surface | The elevations to which water will rise in artesian wells, or wells penetrating confined aquifers; determined by both water pressure and elevation of the aquifer. |
| pillar | A solid mass of rock left standing to support a mine roof. |
| pintle | Handling fixture on the waste container; a knob welded to one end of the waste container that can be grappled by the handling mechanism in the surface facility or during emplacement or retrieval operations. |
| piper diagram | A trilinear graph designed to represent chemical analyses of water as percentages of total equivalents per liter. |
| placer | A surficial deposit formed by mechanical concentration of mineral particles from weathered debris. The common types are beach placers and alluvial placers. The mineral concentrated is usually a heavy mineral such as gold, cassiterite, or rutile. |

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| planar-rotational faults | A group of parallel faults in which both the faults and beds rotate together during extension, much like tilting dominos. These types of faults generally have no penetrative deformation, pressure solution, or bedding-plane slip associated with them. |
| plane-strain | A state of strain in which all displacements that arise from deformation are parallel to one plane, and the strain normal to that plane is zero. |
| plate | A segment of the lithosphere that is internally rigid and moves independently over the interior, meeting in convergence zones and separating at divergence zones. |
| plate bearing | A procedure performed in small tunnels or adits to measure the deformation characteristics of a rock mass. |
| plug | A sealing component used for structural support. |
| plugback | To cement off a lower section of casing in a drill-hole to block fluids below from rising in the casing to a higher section being tested. |
| plunge (structural geology) | The inclination of a fold axis or other geologic structure, measured by its departure from horizontal. |
| pluvial | Pertaining to rain or to precipitation. Also said of a climate characterized by relatively high precipitation. |
| pneumatic testing | Pressure testing of a process vessel by the use of air pressure. |
| Poisson's ratio | The ratio of the lateral strain to the longitudinal strain in a body that has been stressed longitudinally within its elastic limit. |
| population dose | The sum of the radiation doses received by the individual members of a population exposed to a particular source or event. It is expressed in units of man-rem. |
| pore pressure (neutral stress) | The stress transmitted by the fluid that fills the voids between particles of a soil or rock mass (e.g., that part of the total normal stress in a saturated soil caused by the presence of interstitial water). |
| porosity | The ratio of the total volume of interstices in rock or soil to its total volume, expressed as a percentage or as a fraction. |
| postclosure | The period of time after the closure of the geologic repository. |

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| postclosure system guideline | Guideline that establishes waste containment and isolation requirements that are based on U.S. Nuclear Regulatory Commission and Environmental Protection Agency regulations. It is also a qualifying condition. |
| potassium-argon dating (K-Ar) | Determination of the age of a mineral or rock in years. Ratio of radiogenic argon-40 to potassium-40 and the known radioactive decay rate of potassium-40 to argon-40. |
| potential evapotranspiration | The amount of water that would be removed from the land surface by evaporation and transpiration processes if sufficient water were available in the soil to meet the demand. |
| potential field | A field which obeys Laplace's equations, such as gravity, magnetic, or electrical fields. |
| potentially acceptable site | Any site at which, after geologic studies and field mapping but before detailed geologic data gathering, the U.S. Department of Energy undertakes preliminary drilling and geophysical testing for the definition of site location. |
| potentially adverse condition | A condition that is presumed to detract from expected system performance, but further evaluation, additional data, or the identification of compensating or mitigating factors may indicate that its effect on the expected system performance is acceptable. |
| potential Q-scenario | Used to designate an accident scenario in which the probability and dose consequence are sufficiently close to the Q-scenario criteria that a change in assumptions or data used in analyses could cause the criteria to be exceeded. |
| potentiometric surface | An imaginary surface representing the total head of ground water and defined by the level to which water will rise in a well. It is usually represented as a contour map in which each point tells how high the water would rise in a well tapping that aquifer at that point. |
| power spectrum | The series of squared Fourier coefficient values. |
| pozzolan | Siliceous material, such as diatomaceous earth, opaline chert, and certain tuffs, that can be finely ground and combined with portland cement. Portland-pozzolan cements are highly resistant to penetration and corrosion by salt water. |
| preclosure | The period of time before and during the closure of the geologic repository. |

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| preclosure radiological safety | The siting and design considerations important in protecting the public and the repository workers from exposures to radiation during repository operations and prior to repository closure. |
| pressure head | The height of a column of liquid supported, or capable of being supported, by pressure at a point in the liquid. |
| pressure plate apparatus | An instrument used for determining pressure head in unsaturated rock. |
| pressurized water reactor (PWR) | A reactor system that uses pressurized water in the primary cooling system. Steam formed in a secondary cooling system is used to turn turbines to generate electricity. |
| pre-waste-emplacement | Before the authorization of a repository construction by the U.S. Nuclear Regulatory Commission. |
| primary area | The surface location, as indicated on a map, of the principal area that may be suitable for waste emplacement. When projected downward along the location of faults and other geologic features, the boundaries of the primary area encompass the principal region within the target emplacement horizon that is considered potentially suitable for waste emplacement. See "emplacement horizon." |
| primary porosity | The porosity that developed during the final stages of emplacement or that was present within particles at the time of deposition. Primary porosity includes all predepositional and depositional porosity of a particle, sediment, or rock. |
| primer | A cap, tube, or wafer containing percussion powder or compound used to ignite an explosive charge. |
| principal stress | A stress that is perpendicular to one of three mutually perpendicular planes that intersect at a point in a body on which the shearing stress is zero; a stress that is normal to a principal plane of stress. The three principal stresses are identified as least or minimum, intermediate, and greatest or maximum. |
| probable maximum flood | The most severe flood reasonably possible based on comprehensive hydrometeorological application of probable maximum precipitation and other hydrologic factors favorable for maximum flood runoff. |

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| product | A description of a result obtained from a design activity, including, for example; design drawings, a design report, supporting analyses, a report of equipment demonstration, an operations plan, etc. A product of a design activity may be an input item for another design or performance-assessment activity. |
| protected area | An area encompassed by physical barriers and to which personnel access is controlled. |
| proton spinner magnetometer | The proton (hydrogen nucleus) has a magnetic movement because of its spin. The spin axis precesses in the presence of a magnetic field, giving rise to an alternating magnetic field with a characteristic frequency that is proportional to the strength of the applied field. In the magnetometer, a strong field is briefly applied to align the spin axis in a sample of fluid. When the initial pulse stops, precession follows at a particular frequency. The alternating field is detected by a measurement coil, and the frequency is counted to determine the strength of the ambient field. |
| prototype weldments | A model (whose component parts are joined by welding) suitable for use in complete evaluation of form, design, and performance. |
| provenance | A place of origin. The area from which the constituent materials of a sedimentary rock or facies are derived. |
| proxy data | Any geologic evidence of past climate. Paleoclimate can not be directly measured in the field, therefore, evidence collected in the field is used to infer these past climatic parameters. |
| psychrometer | A hygrometer consisting of two similar thermometers with the bulk of one being kept wet so that the cooling that results from evaporation makes it register a lower temperature than the dry one. The difference between the readings constitutes a measure of the dryness of the atmosphere. |
| psychrometric chart | A nomograph for graphically obtaining relative humidity, absolute humidity, and dew point, from wet- and dry-bulb thermometer readings. |
| public radiation safety assessment package | A general approach to the resolution of Issue 2.1 including the following design steps: a design evaluation, identification of radiation source characteristics, a radionuclide transport evaluation, a public radiation exposure calculation, and a performance evaluation for compliance with goals. |

pumping test — (1) Yield of water. A test made with a pump in a new well to determine its water-yielding capacity. Quantities and water levels are recorded during the test period. The test pumping rate is usually greater than that at which water will be required and covers a period sufficiently long to indicate whether the yield can be maintained. (2) Quality of water. Taking water samples during the test to determine by chemical analyses, the chief constituents and organic purity. Tests may extend over about 14 days, and finally a full mineral analysis is often made and may be used to prescribe treatment and purification processes.

pycnometer — A standard vessel often provided with a thermometer for measuring and comparing the densities of liquids or solids.

pyroclastic — Pertaining to clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent. Also, pertaining to rock texture of explosive origin.

pyrophoric — (1) Igniting spontaneously. (2) Emitting sparks when scratched or struck, especially with steel.

Q-list — A list of geologic repository structures, systems, and components that have been determined to be important to safety, waste isolation, or both, and are thereby subject to the highest quality assurance (QA) level (QA Level I) of the formal QA Plan.

Q-scenario — An accident scenario that exceeds a probability of occurrence of $10^{-5}$ per year and causes an offsite dose of 0.5 rem or greater.

qualified site — A site that, having been characterized, is considered to be technically suitable for a repository.

qualifying condition — A condition that must be satisfied for a site to be considered acceptable with respect to a specific guideline.

quality assurance (QA) — all the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily.

Quality Assurance Level I — Those radiological health and safety related items and activities that are important to either safety or waste isolation and that are associated with the ability of a geologic nuclear waste repository to prevent or mitigate the consequences of a process or event that could cause undue risk to the radiological

heath and safety of the public. Items and activities important to safety are those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose either to the whole body or to any organ of 0.5 rem or greater either at or beyond the nearest boundary of the unrestricted area at any time until the completion of the permanent closure of the repository. Activities important to waste isolation are those that must meet the criteria that address postclosure performance of the engineered and natural barriers to prevent the release of radionuclides. The criteria for items or activities important to safety and waste isolation are found in 10 CFR Part 60 and 40 CFR Part 191.

Quality Assurance Level II — Those activities and items related to the systems, structures, and components that require a level of quality assurance sufficient to provide for reliability, maintainability, public and repository worker nonradiological health and safety, repository worker radiological health and safety, and other operational factors that would have an impact on the environment and on U.S. Department of Energy and Yucca Mountain Project Office concerns.

Quality Assurance Level III — Those activities and items not classified as quality assurance (QA) Levels I or II.

quality control — Quality assurance actions that provide a means to control and measure the characteristics of an item, process, or facility to established requirements.

quality factor (radiation) — A measure of the relative biological damage from a given type of radiation related to linear energy transfer (LET).

radar remote sensing — A remote sensing system that has a microwave energy source and a microwave detector for intercepting and measuring returned radar signal. Returned signals are processed to give an image of returned microwave energy, which can be correlated to topography and geologic features. See "side-looking airborne radar."

radial borehole test (azimuthal survey) — A survey method in which potential electrodes are moved along radii about a drillhole containing a fixed current electrode. The second current electrode (infinite electrode) is a great distance away.

radiation dose — The quantity of radiation absorbed per unit of mass by the body or any portion of the body.

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| radiation field intensity | In general, the quantity of radiant energy at a specified location passing perpendicularly through unit area in unit time. |
| radiation zone | An area that contains radioactive materials or radiation field in quantities significant enough to require the control of personnel entry to the area. |
| radioactive decay | A spontaneous nuclear transformation (disintegration) in which nuclear particles or electromagnetic energy (such as alpha particles, beta particles, or gamma photons) are emitted. |
| radioactive-waste facility | A facility subject to the licensing and related regulatory authority of the U.S. Nuclear Regulatory Commission pursuant to Sections 202(3) and 202(4) of the Energy Reorganization Act of 1974 (88 Stat. 1244). |
| radiocarbon dating | The determination of the age of a material by measuring the proportion of the isotope carbon-14 (radiocarbon) in the carbon that it contains. The method is suitable for the determination of ages up to about 60,000 years. |
| radiography testing | A method used to determine flaws in pipe or other metals by use of a source emitting x-rays or gamma rays, which penetrate the metal and are transcribed onto film. |
| radioisotope | A radioactive isotope of an element. |
| radiological environmental monitoring | The measurement of radioactive contaminant concentrations or radiation intensity in the environment. |
| radiological exposures to public | The radiation dose received by the absorption of radiation or the intake of radionuclides by an individual except when that individual is a worker engaged in operations involving the management, storage, and disposal of radioactive waste. |
| radiolysis | The decomposition of molecules (often the water molecule) due to interactions with gamma radiation. |
| radiometric dating | The calculation of the age of a material by a method based on the decay of radionuclides that occur in the material. |
| radionuclide | An unstable radioactive nuclide that decays toward a stable state at a characteristic rate by the emission of ionizing radiation(s). |

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| radionuclide retardation | The process that causes the time required for a given radionuclide to move between two locations to be greater than the ground-water travel time because of physical and radionuclide interactions between the radionuclide and the geohydrologic unit through which the radionuclide travels. See "retardation." |
| raise boring | A mining method by which a vertical circular opening is excavated from the bottom up using a special drill bit. |
| random walk theory | A succession of movements along line segments where the direction, and possibly the length, of each move is randomly determined. |
| reasonably achievable | Mitigation measures or courses of action shown to be reasonable considering the costs and benefits in accordance with the National Environmental Policy Act of 1969. See "as low as reasonably achievable." |
| reasonably available technology | Technology that exists and has been demonstrated, or for which the results of any requisite development, demonstration, or confirmatory testing efforts before application will be available within the required time periods. |
| reasonably foreseeable releases | Releases of radioactive wastes to the accessible environment that are estimated to have more than one chance in 100 of occurring within 10,000 yr. |
| recharge (hydrologic) | The process by which water is added to the zone of saturation, either directly into a geologic formation or indirectly by way of another formation or through unconsolidated sediments. |
| recurrence interval | (1) The average time interval between occurrences of a hydrologic or geologic event of a given or greater magnitude. (2) In an annual flood series, the average interval in which a flood of a given size recurs as an annual maximum. (3) In a partial duration series, the average interval between floods of a given size, regardless of their relationship to the year or any other period of time. This distinction holds even though, for large floods, recurrence intervals are nearly the same on both scales. |
| regulated area | An area to which public access is limited or controlled. |
| regulatory agency | The government agency responsible for regulating the use of sources of radiation or radioactive materials or emissions and responsible for enforcing compliance with such regulations. |

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| relative age | The geologic age of a fossil organism, rock, geologic feature, or event, defined relative to other organisms, rocks, features, or events rather than in terms of years. |
| relative permeability | The ratio between the effective permeability of a given fluid at a partial saturation to the permeability at 100 percent saturation (the absolute permeability). It ranges from zero at low saturation to 1.0 at a saturation of 100 percent. |
| relative porosity | The ratio of the volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage. |
| release limit | A regulatory limit on the concentration or the amount of radioactive material released to the environment; usually expressed as a radiation dose. |
| remanent magnetization | Permanent magnetization induced by an applied magnetic field, causing an alignment of magnetic domains or particles, which is then fixed in the material through the effects of cooling, deposition, mechanical shock, or other process, rendering the material permanently magnetized. |
| remote-handled transuranic (TRU) waste | Transuranic waste that requires shielding in addition to that provided by its container in order to protect people nearby because its surface dose rate (greater than 0.2 rem/hr) precludes safe direct handling. |
| remote sensing | Collection of information about an object by a recording device that is not in physical contact with it. The term is usually restricted to include methods that record reflected or radiated electromagnetic energy, rather than methods that involve significant penetration into the earth. The technique employs such devices as the camera, infrared detectors, microwave frequency receivers, and radar detectors. |
| removal | The removal of emplaced waste for performance confirmation, inspection, analysis, or any other purpose not directly related to public health and safety (and the environment). |
| repository | See "geologic repository." |
| repository area boundary | See "controlled area." |

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| residual gravity | In gravity prospecting, the portion of a gravity effect remaining after removal of some type of regional effect; usually the relatively small or local anomaly components of the total or observed gravity field. |
| residual saturation | The saturation at which the water network in the rock pores becomes disconnected and the water conductivity is zero. |
| residual stress (ambient stress field) | The concept of residual stress is based on the coexistence of locked-in strains, resulting from crystal distortion due to past external loads, and locking strains that constrain them. The residual stresses giving rise to locked-in and locking strains are present in finite bodies with no external loads applied on their boundaries, thus the vector sum of residual stresses within such bodies is zero. The strains are stored by cementation, and physical and chemical reaction between anisotropic grains which occur while under applied stress. |
| residual uncertainties | Those levels of uncertainty remaining after careful investigation, design, and development have been completed. For example, the present uncertainty in seismic hazard to surface facilities can be reduced by a careful program of field investigation and data evaluation, but not to zero uncertainty. |
| resistivity imaging technique | A geophysical prospecting method in which direct measurements are made of the ratio of voltage to current. The current is a function of the conducting property of a rock and is controlled by its water content and its salinity. If these values are high, then its conductivity is also high and its electrical resistivity is low. |
| resistivity survey | Any electrical exploration method in which current is introduced into the ground by two contact electrodes and potential differences are measured between two or more other electrodes. |
| resonant column test | A test to study the effects of variations in stress or strain amplitudes while a cylindrical column of soil is vibrated in either the longitudinal or torsional mode, normally in a triaxial cell. |
| response surface | A nonlinear function that describes the manner in which the output varies with changes in input variable. |

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| restricted area | Any area to which access is controlled by the U.S. Department of Energy for purposes of protecting individuals from exposure to radiation and radioactive materials before repository closure, but not including any areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area. |
| resurgent caldera | A caldera that has been subjected to broad upwarping or doming after formation. Resurgence usually results in formation of a highly faulted structural dome in the center of the caldera. |
| retardation | The act or process that reduces the rate of movement of a chemical substance in a water stream relative to the average velocity of the water. The movement of the chemical substance in the water can be retarded by sorption and desorption reactions, by precipitation and dissolution reactions, and by diffusion into the pore water of the rock matrix. See "radionuclide retardation." |
| retention curve | See "moisture-retention curve." |
| retention pond | An earthen structure designed to hold stormwater runoff; sometimes used to mean an evaporation pond. |
| retrievability | The capability that is provided by the repository system--by means of design approaches, construction methods, and operating procedures--to allow waste retrieval to be performed. |
| retrievability period | The time during which emplaced waste is capable of being retrieved. For design purposes, this period begins with emplacement of the first waste and ends 50 years thereafter at the end of the caretaker period. |
| retrieval | The act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal. |
| retrograde metamorphism | A type of polymetamorphism by which metamorphic minerals of a lower grade are formed at the expense of minerals characteristic of a higher grade metamorphism. A readjustment necessitated by a change in physical conditions (e.g., a lowering of temperature). |

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| reverse air-vacuum drilling | A drilling method using reverse circulation (down the annulus and up the drill pipe) with air as circulation medium, to avoid fluid loss into the formation and to provide high quality in situ moisture content data. Circulation is forced by drawing a vacuum on the drill pipe at the surface. |
| reverse drilling (rotary) | A method of drilling in which drilling fluid is forced to the bit by way of the annulus, around the drill pipe, and flows back to the surface up the inside of a rapidly rotating drill stem. |
| Richard's equation | The mathematical equation generally used to describe flow through an unsaturated porous medium. |
| Richter magnitude | See "Richter scale." |
| Richter scale | A numerical scale of the energy released by an earthquake, as measured on an instrument (e.g., a seismometer) that transforms the mechanical effects of earth shocks into electrical signals. |
| ring-fracture zone | A steep sided fault pattern cylindrical in outline and associated with caldera subsidence. |
| rock burst | A sudden yielding that occurs when a volume of rock is strained beyond its elastic limit and the accompanying failure is such that the accumulated energy is released instantaneously. A rock burst can vary from the splitting off of small slabs of rock to the collapse of large pillars, roofs, or other massive parts of a mine. |
| rock quality designation (RQD) | A drill core quality rating used as a parameter for classification of rock quality. Evaluated by determining the percentage of recovery of core in lengths that are greater than twice the diameter of the core. |
| rock varnish | See "cation-ratio dating." |
| roof loading | Any covered structure, not classified as a bridge, that constitutes a transverse drain, waterway or other opening under a road, railroad canal, or similar structure. |
| rotary drilling | A drilling process consisting of a rotating drill pipe at the bottom of which is attached a hard-toothed drill bit. |
| rubber-balloon method (field density test) | A method to determine field or in situ density of naturally occurring soils or fill materials for the control of compaction. |

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| rubidium-strontium dating | Determination of an age for a mineral or rock in years based on the ratio of radiogenic strontium-87 to rubidium-87 and the known radioactive decay rate of rubidium-87. |
| rupture zone | A zone in the lithosphere characterized by brittle or ductile fracturing of rock. |
| sand-cone method | A standardized method for measuring bulk density of granular materials including alluvium, whereby a bulk sample is weighed in a conical vessel of prescribed dimensions. |
| saturated conductivity | See "hydraulic conductivity." |
| saturated flow | Ground-water flow through the saturated zone. |
| saturated zone | That part of the earth's crust beneath the water table in which all voids, large and small, are ideally filled with water under pressure greater than that of the atmosphere. |
| scaling | (1) The removal of loose rock from a newly blasted wall or roof. (2) The term scaling can be used to describe, for example, the conducting of experiments, previously done at a laboratory scale, at a field scale (the scaling of experiments). Differences in the results of the experiments may be due to a scaling effect. |
| scanning Auger technique | A surface analytical technique. |
| scanning-transmission electron microscope | A type of electron microscope that has the capability of forming the electron beam into a fine probe and scanning it across a thin specimen. The transmitted scanned beam is collected below the specimen by a solid-state detector and is reproduced electronically as an image on a cathode-ray tube. |
| scarification | The process of breaking up and loosening the surface of a material. |
| scouring | An erosional process, especially by moving water. |
| seafloor spreading ridge | An extensional ridge associated with a continuous seismic mountain range extending through the ocean where oceanic crust is increasing by convective upwelling of magma. The new material moves away at a rate of 1 to 10 cm/yr. |
| seal | An engineered component that reduces water flow. |

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| secondary compression | The reduction in volume of sediments under constant pressure that results from changes in the internal structure of the sediments. |
| secondary creep | Time-dependent strain occurring under constant stress at a minimum and almost constant rate. |
| secondary mineral | A mineral formed later than the rock enclosing it, usually at the expense of an earlier-formed primary mineral, as a result of weathering, metamorphism, or solution. |
| secondary porosity | The porosity developed in a rock after its deposition or emplacement, through such processes as solution or fracturing. |
| Secretary | The Secretary of Energy. |
| sediment yield | The amount of material eroded from the land surface by runoff and delivered to a stream system. |
| seep | An area, generally small, where fluid percolates slowly to the land surface. For water, it may be considered as a synonym of seepage spring, but it is used by some for flows too small to be considered as springs. |
| seepage face | A belt along a slope, such as the bank of a stream, along which water emerges at atmospheric pressure and flows down the slope. |
| seiche | A periodic oscillation of a body of water whose period is determined by the resonant characteristics of the containing basin as controlled by its physical dimensions. These periods generally range from a few minutes to an hour or more. |
| seismic | Pertaining to, characteristic of, or produced by earthquakes or earth vibrations. |
| seismic acceleration | The acceleration associated with the passage of seismic waves at the surface or subsurface, as applicable. |
| seismic belt | An elongate earthquake zone such as the belts of the circum-Pacific, the Mediterranean and trans-Atlantic, the mid-Atlantic, and the mid-Indian. |
| seismic lines | The route taken on the surface for deploying seismic sources and detectors in the performance of seismic reflection or seismic refraction surveys. |
| seismic loading | A temporary stress generated during a seismic cycle. |

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| seismic pumping | A concept for ground-water movement in response to stress and strain changes associated with seismic activity, for which direct evidence is very sparse or nonexistent. |
| seismic reflection survey | A survey based on measurement of the travel times of waves that originate from an artificially produced disturbance and that are reflected back to the surface at nearly vertical incidence from boundaries separating media of different elastic-wave velocities. |
| seismic refraction survey | A program to map geologic structure by using head waves. Head waves involve energy that enters a high-velocity medium (refractor) near the critical angle and travels in the high-velocity medium nearly parallel to the refractor surface. The objective is to determine the arrival times of the head waves to map the depth to the refractors in which they traveled. |
| seismic velocity | The rate of propagation of an elastic wave, usually measured in kilometers per second. The wave velocity depends on the type of wave as well as the elastic properties and density of the earth material through which it travels. |
| seismogenic | Capable of generating seismic waves and a seismic event of significant magnitude. |
| seismometer | An instrument that detects and measures ground motion and produces a signal proportional to the displacement of the point where the instrument is in contact with the earth. May be used in a broad context to refer also to geophones (output signal proportional to velocity) and accelerometers (proportional to acceleration). |
| seisviewer log | A well log wherein a pulsed, narrow acoustic (sonar) beam scans the borehole wall in a tight helix as the tool moves up the borehole. A display of the amplitude of the reflected wave on a cathode ray tube (television screen) is photographed yielding a picture of the borehole wall to reveal fractures, vugs, etc. |
| self-potential curve | An electric log curve that records changes in natural potential along an uncased borehole. |
| semiarid | Said of a type of climate in which there is slightly more precipitation (25-50 cm) than in an arid climate, and in which sparse grasses are the characteristic vegetation. In Thornthwaite's classification, the moisture index is between -20 and -40. |

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| service main | The drift running parallel to the waste and tuff mains southwest through the longitudinal axis of the underground repository dedicated to equipment and personnel access. |
| settlement | The lowering of the overlying strata in a mine, owing to the extraction of the mined material. |
| settlement plug | A plug of cast concrete or similar material placed within a shaft, anchored to the surrounding bedrock, to provide physical support to overlying backfill in the shaft. |
| Sevier Orogeny | A name proposed by R. L. Armstrong for the well-known deformations that occurred along the eastern edge of the Great Basin in Utah during times intermediate between the Nevadan orogeny further west and the Laramide orogeny further east, culminating early in the late Cretaceous. |
| SH-wave (shear wave) | Shear waves with motion parallel to the free surface. |
| shaft collar | See "collar." |
| shaft liner | A structural lining usually made of steel, concrete, or timber that provides safe rock support and aids in preventing ground water from entering the shaft. |
| shaft pillar | An undisturbed buffer zone surrounding a shaft of sufficient area, so that any possible subsidence in nearby mined areas will not disturb the integrity of the shaft facility. |
| shaft station | A horizontally excavated opening of a shaft at a desired depth. |
| shear | (1) A stress state that produces a strain causing contiguous parts of a body to slide relative to each other in a parallel direction. (2) Surfaces and zones of failure by shear or surfaces along which differential movement has taken place. |
| shear modulus | The ability of atoms in a solid to slide past one another. The higher the value of the shear modulus the more rigid the material. Also referred to as the modulus of rigidity. |
| shear resistance | See "shear strength." |
| shear strength | The internal resistance of a body to shear stress, typically including a frictional part and a part independent of friction called cohesion. |

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| shear stress | That component of stress that acts tangential to the plane through any given point on a body; any of the tangential components of the stress tensor. |
| shear wave (s-wave) | A type of seismic body wave propagated by a shearing motion of material, so that there is oscillation perpendicular to the direction of propagation. It does not travel through liquids or the outer core of the earth. Its speed is 3.0 to 4.0 km/s in the crust and 4.4 to 4.6 km/s in the upper mantle. The "s" stands for secondary, so named because it arrives later than the p-wave (primary body wave). |
| sheave | A large, pulley-type wheel at the top of the headframe that carries the hoist rope. |
| sheet flow (laminar flow) | An overland flow or downslope movement of water taking the form of a thin, continuous film over relatively smooth soil or rock surfaces and not concentrated into channels larger than rills. |
| shelby tube | A thin-shelled tube used to take deep-soil samples. The tube is pushed into the undisturbed borehole and driven into the ground. |
| shield plug | A cylinder of concrete, steel, or other dense material used to plug emplacement boreholes after waste package emplacement. Its main function is to attenuate radiation by providing shielding from the radioactive waste. |
| shielding | The material interposed between a source of radiation and personnel to protect against radiation exposure; commonly used shielding materials are concrete, water, and lead. |
| shielding collar | A component of the shielding closure that provides radiation shielding by extending from the closure to the transporter cask during emplacement or retrieval. |
| shipping cask | A specially designed and certified massive metal container that provides shielding and containment in accordance with Federal and/or international radiological safety rules and regulations for safe transportation of radioactive materials through the public domain. |
| shotcrete | Cement-based compounds sprayed on mine surfaces to prevent erosion by air and moisture and on rock surfaces to stabilize against minor rock falls. Also used to prevent dehydration and decrepitation. |

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| side-looking airborne radar (SLAR) | An airborne radar system in which a long, narrow, stabilized antenna, aligned parallel to the motion of an aircraft or satellite, projects radiation at right angles to the flight path. Returned signals are processed to give an image of returned microwave energy, which can be correlated to topography and geologic features. |
| sieve analysis | Determination of the percentage distribution of particle size by passing a measured sample of soil or sediment through standard sieves of various sizes. |
| sieve deposit | The formation of a coarse-grained mass on an alluvial fan whose material is sufficiently coarse and permeable to permit complete infiltration of water before it reaches the toe of the fan. |
| significant source of ground water | As defined in 40 CFR Part 191, an aquifer that (1) is saturated with water having less than 10,000 milligrams per liter of total dissolved solids, (2)is within 770 meters (2,500 feet) of the land surface, (3) has a transmissivity greater than $3 \times 10^{-5}$ $m^2/s$ (200 gallons per foot per day), provided that any second formation or part of a formation included within the source of ground water has a hydraulic conductivity greater than $1 \times 10^{-6}$ m/s (2 gallons per square foot per day), and (4) is capable of continuously yielding at least 1,600 liters per hour (10,000 gallons per day) to a pumped or flowing well for a period of at least a year; or an aquifer that provides the primary source of water for a community water system. |
| sink | (1) A depression containing a central playa or saline lake with no outlet, as where a desert stream comes to an end or disappears by evaporation. (2) To drill or put down a shaft or borehole. (3) A water lodgement or trap at a pumping station. (4) Generally synonymous with outflows or withdrawal of ground water. |
| sinking deck | A scaffold for staging that is designed for use during shaft sinking, particularly during lining operations. |
| site | A potentially acceptable site or a candidate site, as appropriate, until such time as the controlled area has been established, at which time the site and the controlled area are the same. |
| skin effect | The phenomena in which alterations in permeability in the vicinity of a drill hole are caused by drilling and completion operations. |

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| skip | A basket, bucket, or open car used to raise materials that is mounted vertically or on an incline on wheels, rails, or shafts and hoisted by a cable. |
| slabbing | A stress-induced failure mechanism of the rock around an excavation. |
| Slake-durability | An index test that tests a rock's resistance to mechanical weathering by rotating samples in a sieve mesh drum for 10 minutes and comparing the sample's final weight to its initial weight. |
| slash | A mining technique in which a large-diameter drilled hole is enlarged by using the drill-and-blast method. |
| sleeve | As related to the waste package, a metallic or non-metallic liner that may be located in the emplacement hole to aid in the emplacement and possible retrieval of the waste. |
| slough | Fragmentary rock material that has crumbled and fallen away from the sides of a borehole or mine working. It may obstruct a borehole or be washed out during circulation of the drilling mud. |
| slug flow | Movement of an isolated body of water, such as free water moving downward in the zone of aeration. The term is based on slang for a small amount of liquid, such as a slug of whiskey. |
| slug injection test | A method for determination of the in situ hydraulic conductivity of an aquifer by instantaneous addition of water to a piezometer. |
| snowcourses | A line or a series of connecting lines of regularly spaced observation stations (usually 10 or more) at which snow samples are taken for measuring depth, density, and water equivalent for forecasting subsequent runoff. |
| snowpillows | A device used to record the changing weight of the snow cover at a point. It consists of a fluid-filled bladder or metal container lying on the ground, the internal pressure of which measures the weight of overlying snow. |
| soil aspect | The direction toward which a slope faces with respect to the compass or to the rays of the sun. |

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| soil horizons | A layer of soil that is distinguishable from adjacent layers by characteristic physical properties such as structure, color, or texture, or by chemical composition, including content of organic matter or degree of acidity, or alkalinity. Soil horizons are generally designated by a capital letter, with or without a numerical annotation (e.g., A horizon). |
| soil profile | A vertical section of soil from the surface to the bedrock that can usually be divided into three zones, or horizons, which develop as weathering takes place. The thickness of the soil profile depends on the age of the soil and the climate. The transitions from one zone to another are normally indistinct. |
| soil water | Water in the belt of soil. The upper subdivision of the zone of aeration, limited above by the land surface and below by the intermediate belt. This zone contains plant roots and water available for plant growth. |
| solar constant | The rate at which solar radiant energy is received outside the atmosphere on a surface normal to the incident radiation at the earth's mean distance from the sun. |
| solar radiation | The electromagnetic radiation emitted by the sun. |
| sole fault | A low-angle thrust fault forming the base of a thrust nappe. The basal main fault of an imbrication. |
| solid solution | A single crystalline phase that may be varied in composition within finite limits without the appearance of an additional phase. |
| sols | A colloidal dispersion of a solid in a liquid. |
| solution channel | Tubular or planar channel formed by solution in carbonate rock terranes, usually along joints and bedding planes. It is the main water carrier in carbonate rocks. |
| sonic log | A geophysical log made by an instrument, lowered and raised in a borehole or well, that continuously records, as a function of depth, the velocity of sound waves as they travel over short distances in the adjacent rocks. The log reflects porosity and lithologic changes. |
| sonic velocity log | A geophysical log made by an instrument, lowered and raised in the borehole or well, that continuously records, as a function of depth, the velocity (or inter-time) of sound waves as they travel over short distances in the adjacent rocks. |

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| sorption | A term including both adsorption and absorption. The binding, on a microscopic scale, of one substance to another, such as by adsorption or ion exchange. In this document, the word is especially used for the sorption of dissolved radionuclides onto aquifer solids or waste-package materials by means of close-range chemical or physical forces. |
| sorptive minerals | The minerals (e.g., zeolites) that have the ability to take up large amounts of some guest molecules or ionic species. These molecules or ions can be in aqueous or gaseous form. |
| special nuclear material | (1) Plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material which the U.S. Nuclear Regulatory Commission, pursuant to the provisions of section 51 of the Nuclear Waste Policy Act of 1983, determines to be special nuclear material, but does not include source material, or (2) any material artificially enriched by any of the foregoing but does not include source material. |
| specific activity | The measure of radioactivity as a function of mass. The unit of specific activity is curie per gram. |
| specific capacity (of a well) | The rate of discharge of a water well per unit of drawdown. |
| specific discharge (q/a) | Discharge (hydraulic) per unit area. It is often used to define the magnitude of a flood. |
| specific electrical conductance | The electrical conductivity of water at 25°C, measured in micro-ohms per centimeter. |
| specific gravity | The ratio of the density of a substance to the density of water when both densities are obtained by weighing in air. |
| specific storage | The volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. |
| specific yield | The ratio of the volume of water that a given mass of saturated rock or soil will yield by gravity to the volume of that mass. |
| spectral amplitude | A seismometer whose response is linearly proportional to the acceleration of the earth materials with which it is in contact. |
| spectroscopy | The production and observation of a spectrum and all methods of recording and measuring, including the use of the spectroscope. |

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| spent nuclear fuel | Fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing. |
| spinner magnetometer | A laboratory instrument that continuously rotates the specimen whose remanent magnetism it is measuring, to produce an alternating voltage in a nearby coil by electromagnetic conduction. |
| splay (fault) | One of a series of minor faults at the extremities of a major fault; often associated with rifts. |
| split-barrel sampling (penetration test) | A method for making soil borings with a split-tube (split-spoon) sampler in order to obtain both representative samples of soil for identification and a record of the soil's resistance to penetration by the tube. |
| spud | The beginning of actual drilling operations on a well or borehole; the first abrasion of the soil by the drill, or the first entrance of the drill into the ground; the preliminary boring of a well through earth material down to rock or other solid substrata. |
| stability, repository | The condition resulting from the nature and rates of natural processes affecting the site during the recent geologic past and the expectation that they will be relatively slow and will not significantly change during the next 10,000 yr or jeopardize the isolation of the waste. As defined in 10 CFR Part 60, the nature and rates of natural processes (e.g., erosion and faulting) have been and are projected to be such that their effects will not jeopardize the isolation of the waste. |
| stability (series) | A grouping of minerals according to their persistence in nature (i.e., to their resistance to alteration or destruction by weathering, abrasion, or post-depositional solution (e.g., olivine (least stable), augite, hornblende, biotite (most stable)). The most stable minerals are those that tend to be at equilibrium at the earth's surface. |
| stable isotope | A nuclide that does not undergo radioactive decay. |
| stage (in hydrology) | The height of a water surface above an established datum plane. |
| standard mean ocean water (SMOW) | The mean isotopic composition of sea water; a reference standard for isotopes of oxygen and hydrogen. |

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| standard neutron activation | A method of identifying stable isotopes of elements in a sample by irradiating the sample with neutrons to render the elements radioactive, after which the elements are identified by their characteristic radiations. |
| standoff | A variable distance between a drift wall or floor and the radioactive waste in a horizontal or vertical emplacement borehole. The standoff distance aids in controlling temperatures and radiation levels in the drift. |
| static water table | The average level of ground water that does not vary over time. |
| statistical distribution function | The distribution function, $F(x)$, of a variate $x$ is the total frequency of members with variate values less than or equal to $x$. As a general rule, the total frequency is taken to be unity, in which case the distribution function is the proportion of members bearing values less than or equal to $x$. Similarly, for $p$ variates $x_1$, $x_2$ $...x_p$ the distribution function $F(x_1,x_2,...x_p)$ is the frequency of values less than or equal to $x$, for the first variate, $x_1$, $x_2$ for the second, and so on. |
| statistical dynamical models | These meteorological models include thermodynamic or energy balance models. The equations are often formulated in terms of averages for days, months, years, or longer intervals. |
| statistical moments | See "moments." |
| steel sets | Steel support beams used for ground control in underground mines. |
| stemming | The material (sand, clay, gravel) that fills a shothole after the explosive charge has been inserted, to prevent the explosion from "blowing out" the top of the hole. Also, the process of installing packers or stemming material, in order to isolate an interval of a borehole, usually with a conduit of some type installed between the interval and the surface. |
| stereonet contouring | See "contoured stereonet." |
| stereonet plot | A two-dimensional projection of a hemispherical surface. Therefore, three-dimensional measurements are viewed in two dimensions, lines are plotted as points and planes are plotted as great circles. These plots are useful for determining angular relationships between lines and planes in space. |

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| Stiff diagram | A diagram plotting cations and anions in water and used as a method to show water-composition differences and similarities in total ionic content between water samples. |
| stoichiometry | (1) The application of the laws of definite proportions and of the conservation of matter and energy to chemical activity. (2) The quantitative relationship between constituents in a chemical reaction. |
| storage | Retention of high-level radioactive waste, spent nuclear fuel, or transuranic waste with the intent to recover such waste or fuel for subsequent use, processing, or disposal. |
| storage coefficient | See "storativity." |
| storativity | The volume of water released from storage in a vertical column of 1 square foot when the water table or other potentiometric surface declines 1 foot. In an unconfined aquifer, it is equal to the specific yield. Also called storage coefficient. |
| straddle packer | A set of two or more packers deployed on a string of drill pipe or tubing, to isolate one or more intervals of a borehole. Often provided with some means of opening and shutting hydraulic communication between the pipe and the interval, and between the pipe and the packers. Used for hydrologic testing and for hydraulic fracturing. |
| strandline | (1) The ephemeral line or level at which a body of standing water (e.g., the sea) meets the land; the shoreline, especially a former shoreline now elevated above the present water level. (2) A beach, especially one raised above the present sea level. |
| stratiform deposits | Said of a special type of strata-bound deposit in which the desired rock or ore are strictly coextensive with one or more sedimentary, metamorphic, or igneous layers (e.g., beds of salt or iron oxide, or layers rich in chromite or platinum in a layered igneous complex). |
| stream capture (piracy) | The natural diversion of the headwaters of one stream into the channel of another stream having greater erosional activity. |

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| stress cancellation | In situ stress is often measured by relieving the stress in a volume of rock, measuring the resultant strain or other physical response, then reloading the rock volume under controlled conditions to reverse the response. When the original state of the rock volume is achieved, the applied stress is regarded to be equal to the in situ stress. In this method, stress is applied until the unloading response is canceled. |
| stress drop | (1) Sudden shear displacement accompanied by a sudden reduction in the shear stress on the fault plane. It reflects release of stored strain energy, much of which is radiated as seismic waves. (2) Loss of stress in a loading test. |
| stress province (field) | The state of stress, either homogeneous or varying from point to point and through time, in a given domain. |
| stress raisers | Changes in contour or discontinuities in structure that cause local increases in stress. |
| stress tensor | A description of the state of stress at a point, which involves nine components, referring to three orthogonal coordinate axes. Three components are normal stresses, acting perpendicular to the coordinate planes; the remaining six components are shear stresses acting parallel to the coordinate planes. |
| stress trajectory | A line used to represent a stress field in a diagram, which is parallel to the principal direction of stress. |
| striation | One of a series of parallel, usually straight scratches or smooth furrows developed on a rock surface by tectonic forces, as a result of the abrasion of one projecting rock against another during fault movement. |
| strike rail goniometer | A tool that allows a geologist to measure the strike of a geologic feature in an underground exposure without using a magnetic compass. |
| stringer | A narrow vein or irregular filament in a rock mass of different material. |
| structural grain | The broad, linear arrangement of geologic structures (such as folds and bedding) of a country or region. For example, the arrangement of roughly parallel ridges and valleys often displayed in regions of tilted strata. |

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| study plan | A plan that will describe the coordination of the work in more detail than is given in the discussions at the study level in Section 8.3.1 (site program). |
| subalpine | Of, pertaining to, or inhabiting cool, upland slopes beneath the timber line. Characterized by the dominance of evergreen trees. |
| subduction boundary | An elongate region along which a crustal block descends beneath another crustal block. |
| substantially complete containment | (1) By virtue of the intrinsic properties and design of the waste package components subjected to the range of conditions anticipated in the underground facility, 80 percent or more of the waste packages will retain all their radioactivity for a containment period of 1,000 years after permanent closure of the repository. (2) At any time during the containment period, at least 99 percent of the radioactivity resulting from the original waste emplaced in the underground facility will be retained within the set of waste packages. (3) Any releases from the waste packages that occur during the containment period should be gradual such that releases from the engineered barrier system in any year during this period should not exceed one part in 100,000 of the total inventory of radionuclide activity present in the geologic repository system in that year. |
| subsurface facilities | In this document, the underground facility and the shafts, ramps, boreholes, and shops. |
| suite (igneous) | (1) A set of apparently comagmatic igneous rocks. (2) A collection of rock specimens from a single area, generally representing related igneous rocks. |
| supergene phenomena (secondary enrichment) | The supergene process of mineral deposition; near-surface oxidation produces acidic solutions that leach metals, carry them downward, and reprecipitate them thereby enriching sulfide minerals already present. |
| surface facilities | All repository operations and support facilities located on the surface of the site. |
| surface rupture | Deformation on the surface due to a momentary loss of cohesion or loss of resistance to differential stress and a release of stored elastic energy. |
| surface-wave | A seismic wave that travels along the surface of the earth, or parallel to the earth's surface. Surface waves include Rayleigh waves, Love waves, and coupled waves. |

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| swelling index number | A numerical expression to indicate the relative swelling properties of a sample when heated under standardized conditions. |
| synergism | Cooperative action of discrete agencies such that the total effect is greater than the sum of the two or more effects taken independently. |
| synoptic-scale | Pertaining to simultaneously existing meteorologic conditions that together give a description of the weather; also, said of a weather map or chart that shows such conditions. |
| system | The geologic setting at the site, the waste package, and the repository all acting together to contain and isolate the waste. See "mined geologic disposal system." |
| system element | A subsystem or component of the total mined geologic disposal system to which performance can be allocated for meeting the regulatory and functional requirements. |
| system guideline | The system guidelines of the U.S. Department of Energy's Siting Guidelines (10 CFR Part 960) establishes postclosure and preclosure requirements for a repository system. These requirements are based on U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency regulations. |
| system performance | The complete behavior of a system in response to the conditions, processes, and events that may affect it. |
| system requirements (SR) | The Federal, State, local, U.S. Department of Energy, and Office of Civilian Radioactive Waste Management programmatic requirements that must be met by the prospective mined geologic disposal system (MGDS) at Yucca Mountain during all phases of MGDS development and after MGDS permanent closure. |
| tagging | Labeling radioactive atoms so that their movements can be traced by use of the Geiger tube. |
| tandem accelerator spectrometer (TAMS) | An electrostatic accelerator in which negative mass hydrogen ions generated in a special ion source are accelerated as they pass from ground potential up to a high-voltage terminal. Both electrons are then stripped from the negative ion by passage through a very thin foil or gas cell, and the proton is again accelerated as it passes to ground potential. |
| target horizon | The geologic unit in which it is planned to locate the repository. |

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| tectosilicates | A class or structural type of silicate characterized by the sharing of all four oxygens of the $SiO_4$ tetrahedra with neighboring tetrahedra and with an Si:O ratio of 1:2. Quartz, $SiO_2$ is an example. |
| teleseismology | The aspect of seismology dealing with records made at a distance from the source of the impulse. |
| televiewer logs (tv) | See "seisviewer log." |
| tendon rods | A steel bar or wire that is tension-anchored to formed concrete, and allowed to regain its initial length to induce compressive stress in the concrete before use. |
| tensiometer | An instrument consisting of a porous cup attached to an airtight, water-filled tube. The porous cup is inserted into the soil at the desired depth, where it comes into contact with the soil water and reaches hydraulic equilibrium. The equilibration process involves the passage of water through the porous cup from the tube into the soil. The vacuum created at the top of the airtight tube is a measure of the pressure head in the soil. |
| tensor | Physical quantities that are three-dimensional entities acting over surfaces or through volumes and requiring either six or nine quantities for their description. |
| thermal | A term applied to material properties that govern the flow of heat and resultant temperature of the material, or a term for the analysis of that response (e.g., thermal properties, thermal analysis). |
| thermal conductivity | (1) The time rate of transfer of heat by conduction, through unit thickness, across unit area for unit difference of temperature. (2) A measure of the ability of a material to conduct heat. Typical values of thermal conductivity for rocks range from 3 to 15 millicalories/cm-sec-degree C. |
| thermal decay | Chemical breakdown of a compound or substance at elevated temperature. Simple substances or constituent elements are produced. |
| thermal demagnetization | A technique of partial demagnetization by heating the specimen to a temperature T, then cooling to room temperature in a nonmagnetic space; this destroys a partial thermoremanent magnetization for that temperature interval, but leaves unaffected a partial thermoremanent magnetization for temperature intervals above T. |

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| thermal diffusivity | Thermal conductivity of a substance divided by the product of its density and heat capacity. In rock, the common range of values is from 0.005 to 0.025 $cm^2/s$. |
| thermal loading | The application of heat to a system. Usually measured in terms of watt density. The thermal loading for a repository is the watts per acre produced by the radioactive waste in the active disposal area. |
| thermal/mechanical (units of rock) | A term applied exclusively to the delineation of stratigraphic units based on a combined consideration of their thermal, mechanical, and thermomechanical properties. |
| thermistor | An electrical resistor making use of a semiconductor whose resistance varies sharply in a known manner with temperature. |
| thermocouple | (1) A device consisting of two dissimilar metals joined at two points, the potential difference between the two junctions being a measure of their difference in temperature. (2) An EMF-generating device that responds to temperature changes, formed by joining two dissimilar metals. Most often made by joining two dissimilar metal wires, and used to sense temperature. |
| thermocouple psychrometers | A psychrometer that uses thermocouples to measure temperature depression. See "psychrometer" and "thermocouple." |
| thermodynamic | (1) For geology and rock mechanics, the interacting properties of a geologic system as they are affected by heat and react physically to the stress. (2) For chemistry, thermodynamics refers to the energy evolved and consumed in chemical reactions and the relationship of this energy to equilibrium. The "thermodynamic data base" refers to a compilation of specific thermal properties (e.g., enthalpy, entropy, and free energy) of different chemical species that can be quantified. |
| thermogravimetric analysis (TGA) | A method of analysis that measures the loss or gain of weight by a substance as the temperature of the substance is raised or lowered at a constant rate. |
| thermoluminescence | The property possessed by many substances of emitting light when heated. It results from release of energy stored as electron displacements in the crystal lattice. |

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| thermoluminescent dosimeter (TLD) | A type of dosimeter (or radiation measurement device) containing a "chip" of thermoluminescent material that emits light when subjected to heat. The amount of light emitted is directly proportional to the radiation dose absorbed by the chip, enabling the quantification of this dose. |
| thermomechanical | An adjective applied to the material properties that govern the physical response of a material to applied thermal stress, or to the analysis of that response (e.g., coefficient of thermal expansion thermomechanical analysis). |
| thin section | A fragment of rock or mineral mechanically ground to a thickness of approximately 0.03 mm and mounted between glasses as a microscope slide. This reduction renders most rocks and minerals transparent or translucent, thus making it possible to study their optical properties. |
| thixotropic | The property of certain colloidal substances, to weaken or change from a gel to a fluid when shaken but to increase in strength upon standing. |
| three-component geophone | An instrument that contains at least three detectors and produces three signals that are proportional to the velocity of the earth in three orthogonal directions, where it is in contact with the instrument. |
| thrust | A fault with a dip of 40 or less over much of its extent in which the hanging wall moves up relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature. |
| time domain reflectometry (transient electromagnetic method) | An electromagnetic method in which the waveform of the transmitted signal is a pulse, step function, ramp, or other form and in which measurements are made after changing. This method uses a train of primary pulses with measurements being made during the off-time between pulses. |
| tipping bucket rain gage | A type of recording rain gage. The precipitation collected by the receiver empties into one side of a chamber, which is partitioned transversely at its center and is balanced bistably upon a horizontal axis; when a predetermined amount of water has been collected, the chamber tips, spilling out the water and placing the other half of the chamber under the receiver; each tip of the bucket is recorded on a chronograph, and the record obtained indicates the amount and rate of rainfall. |

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| to the extent practicable | The degree to which an intended course of action is capable of being effected in a manner that is reasonable and feasible within a framework of constraints. |
| tomographic analysis | Analysis by reconstruction of an object from a set of its projections. |
| total magnetic intensity (TMI) log | A geophysical wireline tool that measures the magnitude of the vector resultant of the horizontal and vertical components of the earth's magnetic field as a function of depth in a borehole. Usually incorporating a proton precession magnetometer See "proton spinner." |
| tracer (radioactive) | One of several radioactive materials of short half-life that is introduced to a ground-water system in order to aid studies of ground-water movement. |
| transfer cask | A shielded enclosure for movement of highly radioactive material. |
| transform fault | Horizontal shear fault that terminates abruptly at both ends, but which nevertheless may show great displacement. |
| transformation (crystallography) | The change from one crystal polymorph to another by one of several processes. |
| transient-line source technique | Similar to the "time domain reflectometry"; but, in addition, may be used to determine thermal properties by application of a heating pulse. |
| transition-state theory | A theory that molecules, before undergoing reaction, must form an activated complex in equilibrium with the reactants, and that the rate of any reaction is given by the rate of decomposition of the complex to form the reaction products. |
| transition temperature | Either the temperature at which a substance changes from one state of aggregation to another (a first-order transition), or the temperature of culmination of a gradual change (a second-order transition). |
| transmissivity | The volumetric rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Mathematically it is the product of permeability and the thickness of the zone of the aquifer being measured. |
| transpiration | The process by which water vapor escapes from a living plant and enters the atmosphere. |

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| transporter cask | The cask mounted on the waste transporter that provides shielding while the waste container is being transported from the waste-handling buildings to the emplacement borehole. |
| transuranic (TRU) waste | Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, per gram of waste, with half-lives greater than twenty years, except for (1)high-level radioactive wastes, (2) wastes that the U.S. Department of Energy has determined, with the concurrence of the Environmental Protection Agency Administrator, do not need the degree of isolation required by 40 CFR Part 191, or (3) wastes that the U.S. Nuclear Regulatory Commission has approved for disposal on a case-by-case basis in accordance with 10 CFR Part 61. |
| trenching | The digging of shallow trenches to expose the underlying stratigraphy, structure, etc., for inspection and sampling. |
| Tresca yield criterion | This criterion states that when a material is subjected to increasing stress, it will yield in a ductile fashion when the maximum shear stress attains a value equal to one-half the yield strength of the material. |
| triaxial compression test | A test in which a specimen of rock is subjected to a confining pressure and then loaded axially to failure. |
| trilateration | A method of surveying in which the lengths of the three sides of a series of touching or overlapping triangles are measured (electronically) and the angles are computed from the measured lengths. |
| triple junction | A point or small region where three lithospheric plates meet. |
| tubbing | Cast-iron liner plates for shafts, fabricated to specification, that bolt together to give support to rock. |
| tuff | A compacted pyroclastic deposit of volcanic ash and dust that may contain rock and mineral fragments incorporated during eruption or transport. |
| tuff main | A drift plan to run southwest through the longitudinal axis of the proposed repository that provides access from the surface to the underground facilities for the removal of tuff and exhaust of air during development. |

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| two-phase flow | Flow through porous media in which both liquid and gas coexist in pore channels. |
| two-well convergence test | An aquifer test in which one well is pumped while water levels are monitored in both the pumping well and a nearby well. In a variation of the test, a chemical tracer may be placed in the unpumped well and allowed to migrate into the pumping well. Temporal variations in the concentration of the tracer in the pump's effluent stream are measured properties of the aquifer. |
| two-well recirculating test | See "cross hole recirculation test." |
| ultrasonic testing | A nondestructive testing method that employs high-frequency mechanical vibration energy to detect and locate structural discontinuities or differences and to measure thickness of a variety of materials. |
| unanticipated processes and events | Those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. |
| unconfined aquifer | An aquifer containing ground water that has a water table or upper surface at atmospheric pressure. |
| unconfined compression test | A test in which a rock sample is loaded axially to failure without application of confining pressure. |
| unconfined compressive strength | The load per unit area at which an unconfined prismatic or cylindrical specimen of soil or rock will fail in an unconfined compression test. |
| underground facility | The underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals. |
| undersaturated | Contains less solute than the solution is capable of dissolving under the given conditions. |
| undisturbed performance | The predicted behavior of a disposal system, including consideration of the uncertainties in predicted behavior, if the disposal system is not disrupted by human intrusion or the occurrence of unlikely natural events. |
| uniaxial compression test | See "unconfined compression test." |

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| unit-cell | The smallest volume of parallelepiped within the three-dimensional repetitive pattern of a crystal that contains a complete sample of the atomic or molecular groups that compose this pattern. Crystal structure can be described in terms of the translatory repetition of this unit in space in accordance with one of the space lattices. |
| unrestricted area | Any area, access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters. |
| unsaturated flow | The flow of water under such conditions that the voids of the porous media are only partially filled with water, the remainder of the pore space being taken up by air. |
| unsaturated hydraulic conductivity | Hydraulic conductivity of an unsaturated material. |
| unsaturated zone | The zone between the land surface and the water table. Generally, water in this zone is under less than atmospheric pressure and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies, the water pressure locally may be greater than atmospheric. |
| unstressed aperture | The physical aperture or opening width of a fracture under a condition of zero normal or shear stress applied across the fracture. The condition of zero stress may be approximated by ascertaining that the actual stress transmitted across the fracture is very small with respect to the half-closure stress or shear strength of the fracture. |
| upper plate | The hanging wall of a fault. |
| uranium fuel cycle | The operations of milling uranium ore, chemical conversion, and isotopic enrichment of uranium, fabrication of uranium fuel and reprocessing of spent uranium fuel. |
| uranium-series disequilibrium dating (uranium-series age method) | Calculation of an age in years for Quaternary materials based on the general finding that the decay products uranium-234, thorium-230, and protactinium-231 in natural materials are commonly in disequilibrium with their parent isotopes, uranium-238 and uranium-235, either deficient or in excess. The age is determined from the measured activity ratios of these isotopes. |

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| uranium-thorium method | Calculation of an age in years for geologic material, often zircon, based on the known radioactive decay rate of uranium-238 to lead-206, uranium-235 to lead-207 and thorium-232 to lead-208 whose ratios give three independent ages for the same sample. |
| uranium-trend method | An open-system dating method based on uranium-series decay and the migration of daughter products of uranium-238 through a soil or sediment column. A successful technique in dating Quaternary deposits. |
| usable area | The surface location, as indicated on a map, of that portion of the primary area within which the underground facility can be located. Delineation of the usable area within the primary area will consider overburden thickness; the characteristics of the target emplacement horizon including mechanical and thermal properties of the tuff, thickness, and dip; and mining feasibility. See "primary area." |
| vadose zone | The unsaturated region of soil, or the zone of aeration between the ground surface and the water table. |
| validation (of a computer code) | The documented confirmation of the adequacy, (i.e., suitability for its intended purpose) of the computer code under review--demonstration that what the software does is appropriate to the problem. Validation includes assurance that any physical model, as embodied in software, is a correct representation of the intended physical system or process. |
| van der Waals attraction | The relatively weak attractive forces that act on neutral atoms and molecules and that arise because of the electric polarization induced in each of the particles by the presence of other atoms. |
| variance-reduction techniques | Analytic or numerical techniques applied to reduce the variance of estimates of the statistical moments of a distribution. |
| verification of computer codes | The documented confirmation that the computer code performs exactly the mathematical and logical operations described in the user's manual and other documents. |
| vertical seismic profiling (VSP) | A seismic survey method in which either a mandrel-type wall-locking tool or a hydrophone streamer, is lowered into a borehole on a wireline cable. The seismic source is usually located on the surface but can also be deployed in either the same or an adjacent borehole. |

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| vertical volumetric flux | The amount of water moving through the subsurface in a vertical direction. |
| Vibroseis | Trade name for a seismic method in which a vibrator is used as an energy source to generate a wave train of controlled frequencies. |
| vitric | Said of igneous material that is characteristically glassy, (i.e., contains more than 75 percent glass). |
| volumetric moisture content | Total unit volume of a soil or rock divided into the volume of contained water. |
| waste container | See "container." |
| waste containment time | See "containment period." |
| waste emplacement borehole | A borehole used specifically for emplacement of waste. See "emplacement borehole." |
| waste emplacement envelope | See "emplacement envelope." |
| waste form | The radioactive waste materials and any encapsulating or stabilizing matrix. |
| waste main | A drift running parallel to the tuff and service mains through the longitudinal axis of the proposed underground facility and dedicated to transporting waste. |
| waste management | The planning, execution, and surveillance of essential functions related to the control of radioactive (and nonradioactive) waste, including treatment, solidification, packaging, transportation, initial or long-term storage, surveillance, disposal, and isolation. |
| waste matrix | The material that surrounds and contains the waste and to some extent protects it from being released into the surrounding rock and ground water. Only material within the canister (or drum or box) that contains the waste is considered part of the waste matrix. |
| waste package | The waste form and any containers, shielding, packing, and other absorbent materials immediately surrounding an individual waste container. |
| waste package envelope | See "emplacement envelope." |
| waste standoff | See "standoff." |

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| waste storage envelope | See "emplacement envelope." |
| waste transporter | The vehicle used to move radioactive waste from the waste-handling building to the waste-emplacement borehole in the underground facility. |
| waste type | Refers to spent fuel (such as fuel rod assemblies from boiling water reactor or pressurized water reactor systems) or high-level waste (commercial or defense). |
| water balance (hydrologic budget) | An accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin, aquifer, soil zone, lake, or reservoir; the relationship between evaporation, precipitation, runoff, and the change in water storage, expressed by the hydrologic equation. |
| water-holding capacity | The smallest value to which the water content of a soil can be reduced by gravity drainage. |
| water of hydration | Water that is chemically combined in a crystalline substance, but that may be driven off by heat. |
| water potential | The total energy with which a rock matrix holds a unit weight of pore fluid. |
| water saturation method | A method used for determining porosity of a rock sample. |
| water table | That surface in a body of ground water at which the water pressure is atmospheric. |
| water yield | The runoff from a drainage basin; precipitation minus evapotranspiration. |
| well completion | The final sealing off of a drilled well (after drilling apparatus is removed from the borehole) with valving, safety, and flow-control devices. |
| wet-bulb depression | The difference in degrees between the dry-bulb temperature and the wet-bulb temperature. |
| wet-bulb temperature | Temperature at which water evaporating into air can bring the air to saturation adiabatically at that temperature; a measure of the evaporating capacity of air. |
| wet-chemical analysis | Any of the methods for chemical determinations using water or other liquids as part of the process. |

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| Whittemore pin measurements | The Whittemore gauge in a dial micrometer with resolution of about 2.5 microns and a nominal gauge length of 25 cm. Specially prepared pins are anchored about 25 cm apart on the exterior surface of the measured specimen or rock mass, and the Whittemore gauge is used to manually measure any relative movement. |
| whole rock sample | A sample in which a portion of the rock, rather than individual minerals, is used for analysis. For certain types of analysis (e.g., in the rubidium-strontium age method), it is preferred. |
| wick | To carry (as moisture) by capillary action. |
| wind rose | A diagram to illustrate the frequency with which wind blows from the various points of the compass. |
| windshield survey | Recording activities of interest in a chosen area by means of observation from a motor vehicle. |
| working level | Any combination of the short-lived radon daughters in one liter of air that will result in ultimate emission of $1.3 \times 10^5$ MeV (million electron volts) of potential alpha energy, and exposure to these radon daughters over a period of time is expressed in terms of "working level months." Inhalation of air containing a radon daughter concentration of 1 working level for 173 hours results in an exposure of 1 working level month. |
| wrench fault | A lateral fault in which the fault surface is more or less vertical. |
| x-ray diffraction (XRD) | A qualitative analytical technique that detects and interprets the diffraction of a beam of x-rays, usually by the three-dimensional periodic array of atoms in a crystal that has periodic repeat distances (lattice dimensions) of the same order of magnitude as the wavelength of the x-rays. This technique is most widely used for qualitative identification of crystalline substances. |
| x-ray fluorescence (XRF) | A type of x-ray emission spectroscopy in which the characteristic x-ray spectrum of a substance is provided by using x-rays of short wavelength to induce the substance to emit x-rays of a longer wavelength. This technique is most widely used for the quantitative (chemical) identification of crystalline substances. |
| xeric | Said of a habitat characterized by a low or inadequate supply of moisture. |

xerophyte — A plant with very low water requirements.

Young's modulus — A linear relationship of stress and strain in an elastic material under tension or compression loading.

zeolites — A group of hydrous aluminosilicate minerals containing sodium, calcium, barium, strontium, and potassium, and characterized by their ease of exchange of these ions.

Zircaloy — An alloy whose major constituent is zirconium, used as cladding material for nuclear fuel rods.

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| A&E | Administration and engineering |
| A/E | architect/engineer |
| ABC | acoustic borehole compensated |
| ACD | advanced conceptual design |
| ACGIH | American Conference of Governmental Industrial Hygienists |
| ACM | alternative conceptual model |
| AEC | Atomic Energy Commission (now the DOE) |
| AFY | acre-feet per year |
| AGCM | atmospheric general circulation model |
| AGU | American Geophysical Union |
| ALARA | as low as is reasonably achievable |
| ANSI | American National Standards Institute |
| AO | annotated outline |
| APD | areal power density |
| API | American Petroleum Industry |
| APS | autocorrelated photon spectroscopy |
| ARM | anhysteritic remanent magnetization |
| ASTM | American Society of Testing Materials |
| AW | artificially prepared ground water |
| AWC | available water holding capacity |
| AWWA | American Water Well Association |
| BCL | Battelle Columbus Laboratory |
| BDG | borehole deformation gauge |
| BET | Brunauer-Emmett-Tesler (surface area measurements) |
| BFn | Bullfrog nonwelded unit |
| BHC | borehole compensated |
| BHD | borehole deflectometer |
| BHP | broke horsepower |
| BHT | bottom hole temperature |
| BLM | Bureau of Land Management, U.S. Department of the Interior |
| B.P. | before present |
| BSM | borehole stress meters |
| BWIP | Basalt Waste Isolation Project |
| BWR | boiling water reactor |
| CAA | construction authorization application |
| CAM | constant air monitor |
| CCDF | complementary cumulative distribution function |
| CCL | casing collar locator (log) |
| CDF | cumulative distribution function |
| CDR | conceptual design report |
| CEC | cation exchange capacity |
| CFR | Code of Federal Regulations |
| CHLW | commercial high-level waste |
| CHnv | Calico Hills nonwelded vitric unit |
| CHnz | Calico Hills nonwelded zeolitic unit |
| CH-TRU | contact-handled transuranic waste |
| CIT | computed impedance tomography |
| CL | concentration limits |
| CLAMS | Common Los Alamos Mathematical Software |

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| CLI | Core Laboratories Inc. |
| CLIMAP | Climate: Long-range Investigation Mapping and Prediction |
| CMSO | California Administrative Code Safety Order |
| COCORP | Consortium For Continental Reflection Profiling |
| CPD | Contracts and Property Division (Yucca Mountain Project Office) |
| CPDB | conceptual perimeter drift boundary |
| CRRL | calculated release rate limit |
| CRT | cathode ray tube |
| CSF | core storage facility |
| CTM | container transport mechanism |
| CTRW | commercial transuranic waste |
| CTSO | California Administrative Code Tunnel Safety Order |
| CY | calendar year |
| DAS | data acquisition system |
| DB | dry bulb |
| dBA | decibel (A-weighting network) |
| DBC | density borehole compensated (log) |
| DBE | design basis earthquake |
| DBR | demonstration breakout room |
| DCF | dose conversion factor |
| DHLW | defense high-level waste |
| DIFL | dual induction focused log |
| DNAG | Decade of North American Geology |
| DOA | U.S. Department of Agriculture |
| DOC | U.S. Department of Commerce |
| DOD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| DOE/HQ | U.S. Department of Energy, Headquarters |
| DOE/NV | U.S. Department of Energy, Nevada Operations Office |
| DOI | U.S. Department of the Interior |
| DOT | U.S. Department of Transportation |
| DPBM | development prototype boring machine |
| DRE | dense rock equivalent |
| DRI | Desert Research Institute |
| DRI | double-ring infiltrometer |
| DSC | differential scanning calorimetry |
| DST | drill stem test |
| DTA | differential thermal analysis |
| DTRC | dual-tube reverse circulation |
| E-log | electric log |
| EA | environmental assessment |
| EBM | energy balance model |
| EBS | engineered barrier system |
| ECP | Environmental Compliance Plan |
| EG&G | Edgerton, Germeshausen & Grier, Inc. |
| EIS | environmental impact statement |
| EMF | electromagnetic field |
| EMMP | Environmental Monitoring and Mitigation Plan |
| ENP | epithermal neutron porosity (log) |
| EPA | U.S. Environmental Protection Agency |
| EPPM | expected partial performance measure |
| EPR | electrochemical potentiokinetic reaction |
| ES | exploratory shaft |

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| ES | electrical survey |
| ESF | exploratory shaft facility |
| ESG | Environmental Systems Group |
| ESTP | Exploratory Shaft Test Plan |
| ETP | Engineering Test Plan |
| F&S | Fenix and Scisson, Inc. |
| FC | favorable condition |
| FDD | formation density dual proximity (log) |
| FDL | formation density log |
| FITS | facilities important to safety |
| FOM | Figure of Merit |
| FPC | final procurement and construction |
| FPCD | final procurement and construction design |
| FY | fiscal year |
| GCM | general circulation model |
| GCM | global climate model |
| GCMS | gas chromatograph mass spectrometer |
| GDS | geologic disposal system |
| GFDL | Geophysical Fluid Dynamics Laboratory |
| GR | Generic Requirements |
| GRD | Generic Requirements document |
| GROA | general repository operations area |
| GSA | Geological Society of America |
| gtm | gross ton miles |
| GTP | Generic Technical Position |
| GWTT | ground-water travel time |
| HDO | deuterium tagged water |
| HFU | heat flow unit |
| HLF | higher-level findings |
| HLW | high-level waste |
| HTO | tritium tagged water |
| IAPD | initial areal power density |
| ICP | inductively coupled plasma (spectrometer) |
| IDS | integrated data system |
| IES | induction electrical survey (log) |
| IGSCC | intergranular stress corrosion cracking |
| INAA | instrumental neutron activation analysis |
| IRM | isothermal remanent magnetization |
| IRS | issue resolution strategy |
| IS | induction survey (log) |
| ISRM | International Society for Rock Mechanics |
| ITS | important to safety |
| JSA | job safety analysis |
| LA | license application |
| LAD | license application design |
| LANL | Los Alamos National Laboratory |
| LBL | Lawrence Berkeley Laboratory |
| LET | linear energy transfer |
| LGSX | long gage surface extensometer |
| LLNL | Lawrence Livermore National Laboratory |
| LLW | low-level waste |
| LPRS | large plot rainfall simulation |
| LR | leach rate |
| LWR | light water reactor |

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| M | magnitude (Richter scale) |
| Ma | million years ago |
| MAP | mean annual precipitation |
| MAT | mean annual temperature |
| MGDS | Mined Geologic Disposal System |
| MGDSR | Mined Geologic Disposal System Requirements |
| ML | local magnitude |
| MM | modified Mercalli (scale of earthquake intensity) |
| MMI | modified Mercalli intensity |
| MMP | meteorological monitoring plan |
| MP | Management Plan |
| MP | multipurpose |
| MPBH | multipurpose borehole |
| MPBX | multiple-point borehole extensometer |
| MPC | maximum permissible concentration |
| MPZ | modified permeability zone |
| MSCFD | million standard cubic feet per day |
| MSL | mean sea level |
| MT | magnetotelluric (sounding method) |
| MT | magnetotelluric (geophysical survey method) |
| MT | metric tons |
| MTHM | metric tons of heavy metal |
| MTL | main test level |
| MTU | metric tons of uranium |
| MWD | megawatt-days |
| NAA | neutron activation analysis |
| NAAQS | Nevada Ambient Air Quality Standard |
| NAFB | Nellis Air Force Base |
| NAFR | Nellis Air Force Range |
| NAS | National Academy of Sciences |
| NBC | neutron borehole compensated (log) |
| NBS | National Bureau of Standards |
| NBS | natural barrier system |
| NCAR | National Center for Atmospheric Research |
| NEA | Nuclear Energy Agency |
| NEIC | National Earthquake Information Center |
| NEPA | National Environmental Policy Act |
| NGI | Norwegian Geotechnical Institute |
| NLI | elemental leaching |
| NNL | neutron-neutron log |
| NNWSI | Nevada Nuclear Waste Storage Investigations (Project); former name of the Yucca Mountain Project |
| NOAA | National Oceanic and Atmospheric Administration |
| NRC | U.S. Nuclear Regulatory Commission |
| NRDA | Nevada Research and Development Area |
| NRDS | Nuclear Rocket Development Station |
| NRM | natural remanent magnetization |
| NRS | Nevada Revised Statute |
| NSTF | near-surface test facility |
| NTS | Nevada Test Site |
| NUREG | NRC regulation (or position preface) |
| NVO | Nevada Operations (DOE) |
| NWPA | Nuclear Waste Policy Act of 1982 |
| NWPAA | Nuclear Waste Policy Amendments Act of 1987 |

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|---|---|
| NWPO | Nevada Nuclear Waste Project Office (State agency) |
| OCRWM | Office of Civilian Radioactive Waste Management (DOE) |
| OGR | Office of Geologic Repositories (DOE) |
| ONWI | Office of Nuclear Waste Isolation |
| ORNL | Oak Ridge National Laboratory, Oak Ridge, Tennessee |
| PAC | potentially adverse condition |
| PI | principal investigator |
| PIP | Prototype Investigation Plan |
| PIXE | particle induced x-ray emission |
| PMC | percent of modern carbon |
| PMF | probable maximum flood |
| PNL | Pacific Northwest Laboratories |
| POC | Project Overview Committee |
| PPW | Prow Pass welded unit |
| PQM | Project Quality Manager |
| PRAM | preclosure risk assessment methodology |
| PT | Paintbrush Tuff |
| PWBS | Project Work Breakdown structure |
| PWR | pressurized water reactor |
| QA | Quality Assurance |
| QAD | Quality Assurance Division |
| QAL | Quaternary Alluvium |
| QALA | Quality Assurance Level Assignment |
| QALAS | Quality Assurance Level Assignment Sheet |
| QAPP | Quality Assurance Program Plan |
| QC | Quality Control |
| R&D | research and development |
| RBT | radial borehole tests |
| RCD | reference conceptual design |
| $R_d$ | sorption ratio |
| REECo | Reynolds Electrical & Engineering Co., Inc. |
| REV | representative elementary volume |
| RH-TRU | remote-handled transuranics |
| RIB | reference information base |
| RMM | regional mesoscale model |
| RMP | Radiological Monitoring Plan |
| RMS | root mean square |
| RQD | rock quality designation |
| SAIC | Science Applications International Corporation |
| SAR | safety analysis report |
| SBIP | Surface Based Investigations Plan |
| SCC | stress corrosion cracking |
| SCP | Site Characterization Plan |
| SDM | sequential drift mining |
| SDR | Subsystem Design Requirements |
| SDRD | Subsystem Design Requirements Document |
| SEM | scanning electron microscope |
| SEPDB | Site and Engineering Properties Data Base |
| SF | spent fuel |
| SGBSN | Southern Great Basin Seismic Network |
| SIP | scientific investigation planning document |
| SL | sea level |
| SLAR | side-looking airborne radar |
| SMOW | standard mean ocean water |

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| SNGBZ | Sierra Nevada-Great Basin Boundary Zone |
| SNL | Sandia National Laboratories |
| SNSZ | Southern Nevada Seismogenic Zone |
| SOC | SCP Overview Committee |
| SOP | standard operating procedures |
| SP | self potential (log) |
| SPRS | small-plot rainfall simulation |
| SR | system requirements |
| SRL | Savannah River Laboratory |
| SRPO | Salt Repository Project Office |
| SS&C | structures, systems, and components |
| SST | sea surface temperature |
| SZ | saturated zone |
| TAMS | tandem accelerator spectrometer |
| TBD | to be determined |
| TBM | tunnel boring machine |
| TC | Tiva Canyon Member |
| TGA | thermogravimetric analysis |
| TGSCC | transgranular stress corrosion cracking |
| TLD | thermoluminescent dosimeter |
| TM | thematic mapping |
| TMI | total magnetic intensity (log) |
| TPO | Technical Project Officer |
| TPT | Topopah Spring Member of the Paintbrush Tuff |
| TRU | transuranic |
| TRW | Tram welded unit |
| TSM | Topopah Spring Member |
| TSW | Topopah Spring welded unit |
| TU | tritium units |
| TUFFDB | Tuff Data Base (the computerized data base containing site-related information collected by the Yucca Mountain Project) |
| UNE | underground nuclear explosion |
| UNLV | University of Nevada, Las Vegas |
| UNR | University of Nevada, Reno |
| UDBR | upper demonstration breakout room |
| USBM | U.S. Bureau of Mines |
| USBR | U.S. Bureau of Reclamation |
| USDWS | underground sources of drinking water |
| USGS | United States Geological Survey |
| UV | ultraviolet |
| UZ | unsaturated zone |
| VSP | vertical seismic profiling |
| WB | wet bulb |
| WBS | Work Breakdown Structure |
| WMPO | Waste Management Project Office (former name of the Yucca Mountain Project Office) |
| WMPO/NV | Waste Management Project Office/Nevada Operations |
| WORM | write once ready many |
| XRD | x-ray diffraction |
| XRF | x-ray fluorescence |
| YM | Yucca Mountain |
| YMMGDS | Yucca Mountain mined geologic disposal system |

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